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SAFETY MANUAL FOR WASTEWATER TREATMENT WITH OXYGEN AERATION

by

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16. ABSTRACT

This safety manual provides design, operating, and safety personnel of municipal wastewater treatment plants which use oxygen aeration of activated sludge systems with the knowledge to prevent hazards due to the interaction of the oxygen with combustibles and other hazardous materials which may be dumped or formed in the wastewater. These hazards include fires, explosions, and toxic gases; all injurious to personnel and plant equipment alike. All potential sources of hazardous materials were considered, which led to the inclusion in the manual of (1) the wastewater train (collection, primary treatment and secondary treatment), and (2) the oxygen train (on-site generation or trucked-in supply, storage and injection into the activated sludge system). The concept followed in this manual was to discuss the sources and nature of hazardous wastes, their detection at various stages, and safe design and treatment practices to minimize adverse effects. Consideration was given to the special problems of industrial wastewater which most urban plants must handle, and the organizational side of plant safety. Safety checklists are provided for the major components of all systems in (1) and (2) above.

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

The purpose of this manual is to provide guidance in the design and operation of wastewater treatment plants, using pure oxygen gas for aeration of activated sludge systems, so as to ensure the safety of treatment plant personnel and equipment.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

ABSTRACT

This safety manual provides design, operating, and safety personnel of municipal wastewater treatment plants which use oxygen aeration of activated sludge systems with the knowledge to prevent hazards due to the interaction of the oxygen with combustibles and other hazardous materials which may be dumped or formed in the wastewater. These hazards include fires, explosions, and toxic gases; all injurious to personnel and plant equipment alike. All potential sources of hazardous materials were considered, which led to the inclusion in the manual of (1) the wastewater train (collection, primary treatment and secondary treatment), and (2) the oxygen train (on-site generation or trucked-in supply, storage and injection into the activated sludge system). The concept followed in this manual was to discuss the sources and nature of hazardous wastes, their detection at various stages, and safe design and treatment practices to minimize adverse effects. Consideration was given to the special problems of industrial wastewater which most urban plants must handle, and the organizational side of plant safety. Safety checklists are provided for the major components of all systems in (1) and (2) above.

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METRIC (SI UNITS) CONVERSION TABLE

LENGTH	
1 inch	2.54 cm
1 foot	0.3048 m
AREA	
1 square foot	0.0929 m^2
VOLUME	
1 gallon	$3.785 \times 10^{-3}\ m^3$ = 3.785 liter
1 cubic foot	$0.028317\ m^3$ = 28.317 liter
SLOPE	
ft per ft	meter per meter
VELOCITY	
1 ft per second	0.3048 m/sec
1 ft per minute	5.08×10^{-3} m/sec
FLOWRATE	
1 gallon per minute	$6.3088 \times 10^{-5}\ m^3$/sec
1 cubic foot per minute	$4.7195 \times 10^{-4}\ m^3$/sec
SPECIFIC FLOWRATE	
1 gallon per ft^2 per day	0.04075 m^3/m^2 day
PRESSURE	
1 pound per square inch	$6.895 \times 10^3\ N/m^2$
1 micron (mercury) (0° C)	$0.1333\ N/m^2$
1 inch of water	$2.4906 \times 10^2\ N/m^2$
CONCENTRATION	
BOD	Biochemical oxygen demand, mg/liter
COD	Chemical oxygen demand, mg/liter
TEMPERATURE	
1 degree F	(5/9) degree C (32° F = 0° C)

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INTRODUCTION

Safety in the field of sanitation, as in many other fields, has frequently been taken for granted. The unfavorable safety record in wastewater collection and treatment systems, however, emphasizes the need for stringent safety practices both in the design and in the operation of such facilities.

In the operation of standard air-operated secondary activated sludge process facilities, one has always been confronted with conditions that introduce combustibles as potential hazards. With the advent of oxygen-enriched atmospheres brought about by the injection of pure oxygen rather than air, the presence of combustibles in treatment plants becomes a much more serious potential hazard. In the past, various processes within a treatment plant could be allowed to deviate from the optimum. This occasional laxness in the application of proper procedures resulted in degradation of the effluent. Although this was highly undesirable in a standard air system, it produced no additional hazard other than possible toxic gases. With oxygen, such laxness can no longer be tolerated. The dumping of combustibles into a collection system and the production of combustibles within a treatment system coupled with an enriched oxygen environment now constitute potential hazards of large proportions.

It is the intent of this manual to provide design, operating, and safety personnel with the knowledge that will prevent these potential hazards from becoming real and causing injury to persons and damage to equipment. The emphasis of this manual is on safety, not operation. Related manuals, such as the Water Pollution Control Federation Manual of Practice No. 1 "Safety of Wastewater Works", the Federal Occupational Safety and Health Standards Title 29, Chapter XVII, Part 1910 (18 October 1972), and any related state, county, or city regulations should apply to the overall safety in wastewater treatment plants.

The basic concept followed in this manual was to consider (1) the sources of hazardous wastes, both domestic and industrial, the detection of these wastes at various stages in the collection and treatment systems, and safe design and treatment practices to minimize their adverse effects; (2) the sources of oxygen, be they on-site production plants or tonnage oxygen road vehicles, and the path taken by the oxygen to its introduction into the wastewater stream via any rational oxygen dissolution concept; and (3) the implementation of this manual in terms of the human element, essential in actually realizing safe conditions.

The manual deals with municipal treatment plants accepting domestic and industrial wastes. The considerations just stated indicate that the potential

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sources of hazardous materials that could lead to fires, explosions, or toxicity are to be found throughout the pretreatment plant that includes on-site oxygen supply facilities, and in the collection system that feeds the plant. This means that a total safety system consisting of collection, treatment and oxygen systems must be addressed.

Accordingly, the manual is divided into five Chapters:

I Collection System
II Treatment System
III Treatment of Industrial Wastes
IV Oxygen System
V Personnel Safety Requirements

Even though the emphasis is on the treatment plant, with Chapter II devoted to "normal" sewage and Chapter III to industrial wastes discharged into a municipal system, the collection and oxygen systems must be included in a total safety effort. It is realized that there may be organizational divisions between collection, treatment, and oxygen personnel. It is essential that any divisions be bridged and that there be good coordination between these organizations for the sake of safety.

The need to consider collection and treatment systems together is based on the desire to detect and act on potentially hazardous discharges as close to their source as possible. The following is a general list of areas and equipment found in both systems where hazardous (explosive, toxic, etc.) conditions may develop:

1. Sources of discharge
2. Sewer lines, empty or in use
3. Manholes
4. Dry wells, open and enclosed
5. Wet wells, open and enclosed
6. Pumping rooms, open and enclosed
7. Metering rooms, open and enclosed
8. Open tanks of any type
9. Closed tanks of any type
10. Pipe galleys of any type
11. Lift and pumping stations
12. Pipes (closed, open; empty, or in use)
13. Enclosed screening or comminutor rooms

In these various items of equipment it is desirable to avoid undue residence time that might permit anaerobic conditions to occur, with the resulting production of explosive and toxic compounds. Flow velocities, based on the requirement of moving wastewater adequately to forestall hazardous situations, should be in excess of the following values:

3 ft/sec in sewer lines*

6 to 14 ft/sec in wet wells

4 ft/min in primary sedimentation tanks

3 ft/min in secondary sedimentation tanks

The sections on the oxygen aeration activated sludge reactors are intentionally kept broad, without reference to proprietary designs. Safety recommmendations given by makers of proprietary systems should be compatible with the recommendations of this manual. This includes specific safety features in the operating manuals accompanying the purchase of oxygen generation plants and oxygen aeration activated sludge systems.

It will be found that Chapter IV, Oxygen, is more voluminous and detailed than Chapters I through III. The reasons for this lies in the century or so of development of air separation plants and the use of pure oxygen in industrial processes such as steelmaking and as a rocket oxidant. Much material on safety is available from oxygen producers, trade associations, and aerospace organizations. Selective use was made of these sources, detailed in the Bibliography at the end of Chapter IV.

Chapter V emphasizes the importance of indoctrination of personnel and constant vigilance in the face of changing conditions. This manual should be used as part of an audio-visual safety course to be given experienced, as well as new operators in plants with oxygen aeration.

Checklists have been included prominently in the various chapters, at the end of sections dealing with major subsystems. Portions of text, tables, and figures used more than once have been repeated in full for ease of reading. The contents listings permit ready reference to desired systems and parts of systems.

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*For simplicity, measurements are in standard U.S. measure. Conversions to S.I. units are listed in the metric conversion table.

I. COLLECTION SYSTEM

A. SEWER SERVICE AREA IDENTIFICATION

Prior to designing any wastewater treatment plant, a complete survey should be made to establish and recognize the type of area to be serviced by the plant. This is extremely important because the location of various potentially hazardous discharges relative to the plant location can play an important role in the in-sewer production of combustibles.

In the urban sewer system shown in Figure 1, the industrial complex is distant from the plant. Depending on the type of industry, the waste has considerable time in the sewer system to break down and produce combustible gases that would enter the treatment process. In this type of service area, consideration should also be given to the location and density of gas station complexes. In Figure 1 the gas station complex adjacent to the facility could mean very little lead time after notification of accidental spills or dumps into the sewer system.

A service area such as shown in Figure 2 depicts a different condition. The industrial complex is immediately adjacent to the treatment plant. This has the advantage of lack of time for degradation of wastes in the sewer line. However, there is little lead time to deal with large spills to the system in this situation.

A knowledge of the service area of the plant is an important design factor with oxygen aeration, because of the necessity to preclude or mitigate combustible conditions.

B. IDENTIFICATION OF WASTES

In addition to knowing where potential discharges may occur, it is also very important to know the nature of potential discharges which a facility can expect. For this reason surveys should be made of the strengths (concentrations) and types (organic, hydrocarbon, and inorganic) of the discharges. A knowledge of the strengths is most necessary, because a low-volume discharge can easily be overlooked and yet may have the ability to cause the greatest problem if its strength is high.

The types of discharges are discussed in some detail in the following paragraphs.

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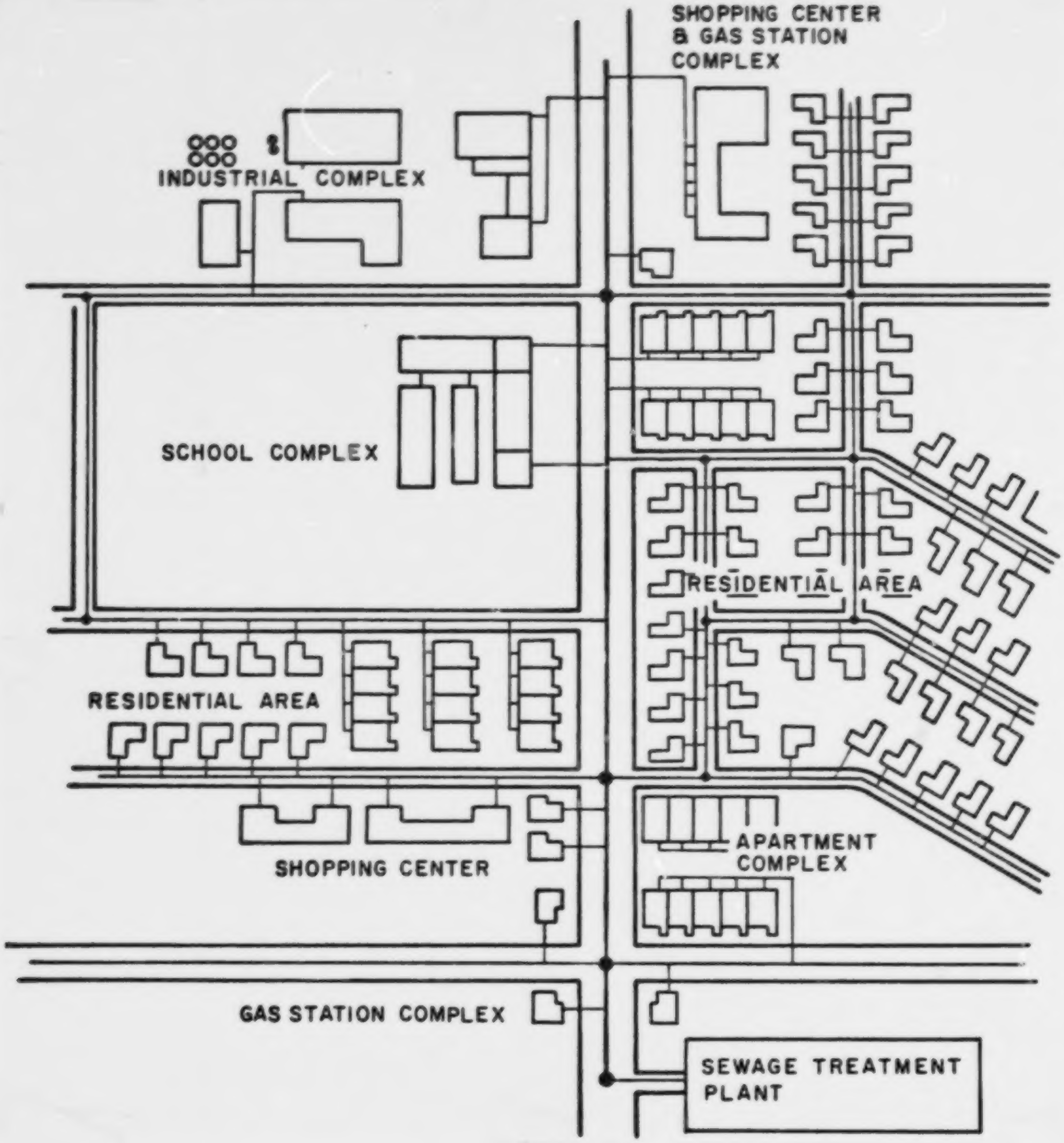
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SCHOOL COMPLEX
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APARTMENT COMPLEX
SHOPPING CENTER
GAS STATION COMPLEX
SEWAGE TREATMENT PLANT

Figure 1. Urban Sewer System With Industrial Sources Distant From Treatment Plant

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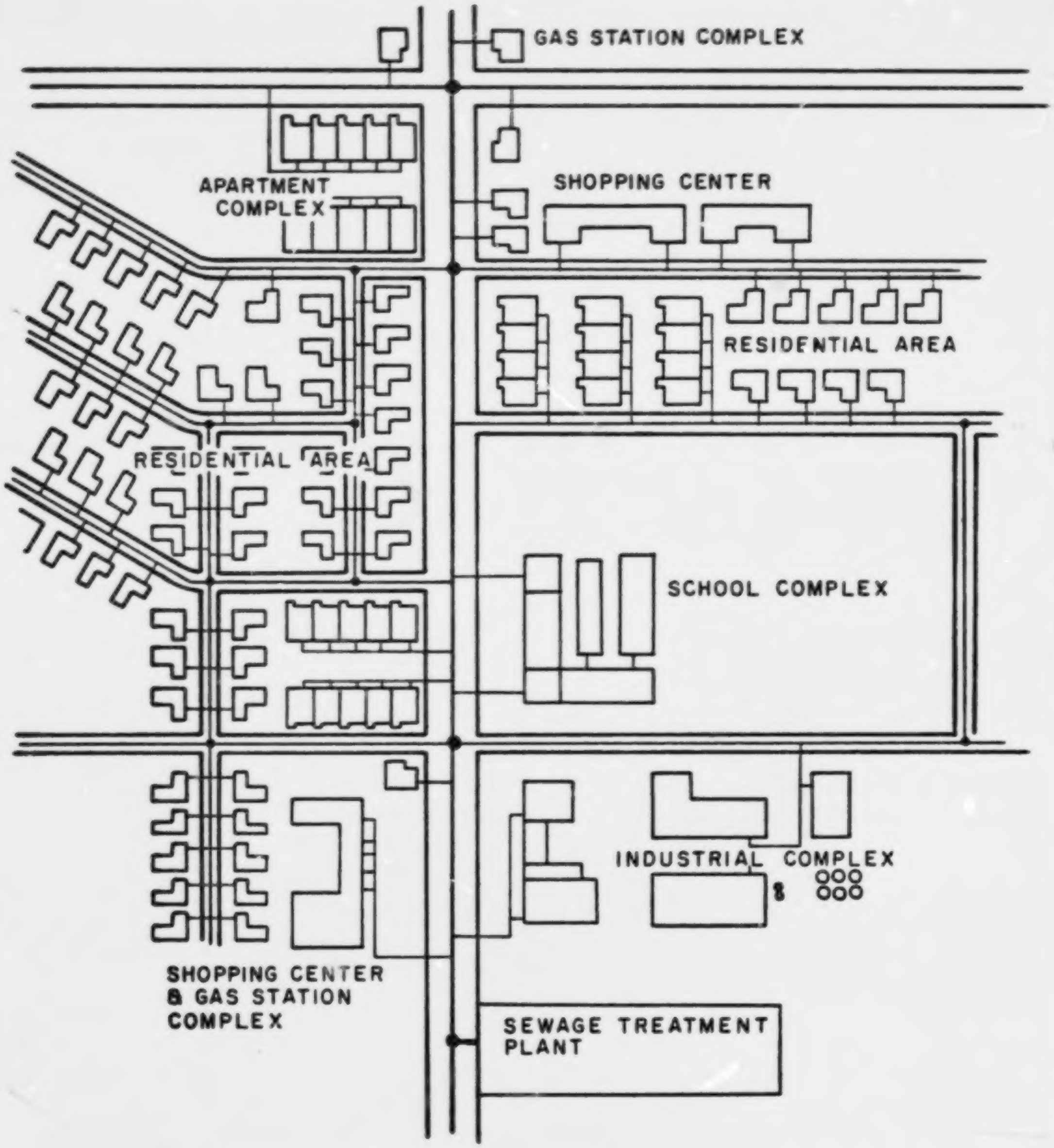
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SEWAGE TREATMENT PLANT

Figure 2. Urban Sewer System With Industrial Sources Near Treatment Plant

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1. Organics

In a sewage of medium strength, about 75% of the suspended solids and 40% of the filterable solids are organic in nature, from animal, vegetable, or industrial sources. When organics enter a plant they already may be partially decomposed due to exposure to anaerobic conditions for a long time, when methane and hydrogen sulfide are formed. Both of these gases are potentially present in any sewer system, and can form explosive mixtures. Organic waste is one of the prime sources for the formation of dangerous gases. Some of the industries that can produce high volumes of organic wastes are those which manufacture the following:

- Agricultural organic fertilizers
- Pharmaceutical materials
- Cosmetics
- Dye materials
- Plastics
- Resins
- Pesticides
- Formaldehyde
- Explosives
- Soap and detergents
- Corn starch

One common type of organic industrial discharge is solvents which can be an immediate problem because they can create an explosion hazard in the sewer system. Chlorinated solvents also create a toxicity hazard in the sewer lines (which are frequently restricted by oils and greases which coat the walls) and they are not amenable to bacteriological sewage treatment. They therefore should be completely excluded from acceptance into a municipal sewage discharge. It is evident that concentrations of more than 10 to 30 ppm of oily materials should not be acceptable as a discharge.

Another common type of waste is from canneries or meat packing houses. These food wastes will put extra loads of grit-heavy organic matter into the sewer lines, if they are not controlled properly before discharge. Any extra-heavy loads that deposit in the lines will, of course, tend to generate methane and sulfide.

2. Hydrocarbons

The principal constituents of hydrocarbon discharges are petroleum products such as gasoline, diesel fuel, heating oils, etc. Many industries which do not produce petroleum products do discharge them. Table 1 lists a few secondary discharges by nonpetroleum industries, such as cutting oils, cooking oils, vapors, solvents, and stripping compounds.

3. Inorganics

Inorganic wastes are chemical substances of mineral origin and may contain carbon and oxygen. Industry could discharge large quantities of inorganic matter that would leave large deposits in the sewer system. These large

TABLE 1. WASTES FROM INDUSTRIAL PROCESSES

Operation	Resulting Wastes	General Means of Control
Tailing and Cutting	Cutting oils Cooking oils	Emulsion breaking, skimming, and resale; Proper incineration; oil separator
Plating		
Electroplating	Cyanides and metals	Removal of heavy metals by electroplating out of solution; Alkaline-chlorination destruction; Incineration to oxides or elemental nitrogen; Cyandid recovery with metal recovery
Electrodeless plating	Metals	Removal by electroplating; Removal by chemical precipitation
	Salt solutions	Neutralization and sedimentation of sulfates, carbonates, etc.
Acid and base treating	Acids	Neutralization and precipitation
Corrosion control oils and chromates	Oils	Same as methods shown for cutting oils
	Chromium Compounds	Chromium compounds by reduction, precipitation and removal by centrifuge, decanting, or filtering
Etching	Acids	Hydrofluoric, nitric, and hydrochloric acids are neutralized and discharged into the main waste stream
Degreasing	Vapor or cold solvent	Solvents are usually reclaimed by distillation; sludges are buried.
Cleaning of metal parts		
Carbon removal (Usually accomplished by use of a phenolic stripper such as orthodichlorobenzene and cresylic acids)	Carbon Compounds	Treated by biological oxidation, ozonation, or incineration; reclamation may be economical

deposits, while they do not form explosive mixtures by themselves, then become excellent traps in which organic waste products can collect and decompose anaerobically, and produce combustible gases, via the breakdown of sulfate ions by bacteria to form sulfides.

The inorganic wastes produced by industry include acids, bases, bulk chemicals, phosphates, and silicones.

Table 2 lists a large number of industries, divided into those discharging organic and inorganic wastes. For each industry, adverse environmental effects, indicated pretreatment, and practicality of biological stabilization (e.g., activated sludge treatment) are stated.

C. SEWAGE FLOW

1. Diurnal Peaks

Diurnal peaks are generally two peaking time periods during any 24-hour period. These are determined by flowrates, times of discharge and distance of the discharge from the plant. At the higher peak period, there probably would be fewer problems in the sewer system due to higher velocities. At the lower flows, problems could develop because of lower velocities which permit deposits to be formed in the sewer lines. These deposits may increase over a period of time and lead to hazardous conditions, if the sewer design incorporated low velocities. Then an effective sewer maintenance program is needed to help control this problem.

However, higher flows and higher solids loading in the unit processes in the treatment plant can cause hazardous problems in any service area due to these higher concentrations and heavier loadings.

Some industries may have shift discharges that could greatly effect the concentrations of combustible material in the system. Canneries could impart a heavier organic load during the nighttime hours. This, coupled with low domestic sewage flows at that time, greatly reduces the dilution capabilities.

Any of these being the case, the designer should recognize them and incorporate a method of "triggering" their detection at the specific troublesome time periods.

2. Seasonal Peaks

Seasonal peaks are actually like diurnal peaks, but instead of being on a daily basis may last 2 to 5 months per year. The same problems will be encountered here as in diurnal peaks, but for a longer duration of time. All operations and methods of detection will have to be adjusted to handle these extra loads of organic and inorganic loadings on the sewage system. All industries at certain times of the year (usually peak plant operation) can also contribute extra loadings of organics, combustibles, and inorganic material. During these periods, operational personnel should be especially aware of the higher potential for troublesome dumps of undesirable wastes.

TABLE 2. INDUSTRIAL WASTE CHARACTERISTICS AND TREATABILITY

Source of Industrial Waste	Possible Adverse Effects on Environment	Type of Pretreatment Indicated	Biological Stabilization Practical
Organic			
Beverage Manufacturing Canneries	Oxygen depletion Suspended solids Oxygen depletion	Aeration Aeration Sedimentation	Yes Yes
Cereal Processing, Cosmetics	Oxygen depletion Toxicity, color, oils and greases	Aeration Grease separation Aeration	Yes Yes
Fertilizers	Aquatic plant growth excessive	Sedimentation Neutralization	Yes
Foods (general) Laundries	Oxygen depletion Alkalinity Oxygen depletion Foam production	Aeration Neutralization Aeration	Yes Yes
Meat packing and processing	Oxygen depletion	Aeration Sedimentation	Yes
Milk and products	Oxygen depletion	Aeration Emulsion breaking Neutralization Grease separation	Yes
Paints	Color, suspended solids Oils and greases Oxygen depletion		
Paper	Suspended and dissolved solids, oxygen depletion, color	Aeration and sedimentation Screening	Yes
Pesticides	Toxics Oxygen depletion	Aeration	Partially

TABLE 2. INDUSTRIAL WASTE CHARACTERISTICS AND TREATABILITY (Continued)

Source of Industrial Waste	Possible Adverse Effects on Environment	Type of Pretreatment Indicated	Biological Stabilization Practical
Petroleum	High salt content Oils and greases COD.	Grease separation Grit removal Aeration	Partially
Pharmaceuticals	Toxic Oxygen depletion	Aeration	Partially
Plastics	Toxic Oxygen depletion	Sedimentation Aeration	Partially
Rubber	Dissolved solids Toxic	Sedimentation	Partially
Sugar	Oxygen depletion Suspended solids	Screening Aeration Sedimentation	Yes
Tanning	Toxicity, color Suspended solids Oxygen depletion	Screening Bleaching Sedimentation Aeration	Yes
Textiles	Toxicity, color Suspended solids Oxygen depletion	Screening Aeration Sedimentation Bleaching	Yes
Wood products	Toxicity, color Suspended solids Oxygen depletion	Screening Bleaching	Yes
Wool processing	Oxygen depletion Oil and grease Alkalinity	Grease separation Grit removal Neutralization	Yes
Inorganic			
Carbon products	Suspended solids Toxicity	Filtration	No

TABLE 2. INDUSTRIAL WASTE CHARACTERISTICS AND TREATABILITY (Concluded)

Source of Industrial Waste	Possible Adverse Effects on Environment	Type of Pretreatment Indicated	Biological Stabilization Practical
Brass	Alkalinity Suspended solids	Neutralization Sedimentation	No
Metal fabrication	Oil and grease Suspended solids Toxicity	Grease separation Sedimentation	No
Metal Processing	Toxicity, color Dissolved and Suspended solids	Grease removal Neutralization Aeration Sedimentation	No
Mining	Suspended solids Toxicity, acidity	Sedimentation Neutralization	No
Photographic work	Toxicity Dissolved solids	Neutralization	No
Pigments and dyes	Color, toxicity Suspended solids	Bleaching Sedimentation	No
Radioisotopes	Toxicity Radioactivity	Ion exchange	No

D. COLLECTION SYSTEM EVALUATION

Although industrial dumps are for the most part considered to be the culprit in contributing combustible material, the sewer agency itself can cause or manufacture its own problems. A poorly designed and a poorly maintained pure domestic system can suffer a continuing severe combustible problem. Some of the items that should be closely looked at in both old and new sewer systems when coupled with an oxygen aeration treatment facility are liquid velocity, slope, and retention time.

Severe problems arise in sewer systems where flows are sluggish or the wastewater is contained for some time in full pipes out of contact with air. There is practically no buildup of combustibles in partly filled small sewers flowing at a velocity of 3 ft/sec or more. In large trunks, buildup does occur even at considerably higher velocities, but then the rate of buildup is slow. The major design considerations for a sanitary sewer include estimation of the maximum rates of sewage flow, evaluation of the local factors that may effect the hydraulic operation of the system, and evaluation of alternative designs. It is desirable to maintain a velocity of 3.0 ft/sec or more whenever practicable, also in inverted siphons, to which access for cleaning is difficult. Slopes corresponding to mean velocities as low as 1.5 ft/sec have been used successfully in some special cases, but sewers at such slopes must be built with great care, and their interior surface must also be finished with great care, to achieve successful working conditions. It is desirable, therefore, to use slopes that will result in self-cleansing velocities in all cases.

The increase in cost of construction due to steeper slopes will be less than the added cost of maintaining the sewers if they are laid on flatter slopes. This is recommended because such maintenance work if neglected, can result in a substantial deposits which can be an area in which explosive gases could develop.

Where slopes are comparatively flat, the sewer sections and slopes should be designed so that the velocity of flow will increase progressively, or at least will be maintained constant, in passing from the inlet to the outlet of the sewer. It is seldom possible to attain this condition fully, however, due to topographical characteristics. In general, the minimum slopes listed below for small pipe sewers in a sanitary system have been found to be suitable.

Pipe Diameter, inches	Slope, ft/ft
8	0.0040
10	0.0030
12	0.0022
15	0.0015
18	0.0012
21	0.0010
24	0.0009
27 and larger	0.0008

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The total retention time may be difficult to control because discharges may be at some distances. A flow from a distance of approximately 50 miles would take approximately 24 hours to reach a treatment plant. This long retention time, can be tolerated if considerable maintenance and cleaning is done in lines in the outlying areas. The less time wastes remain in the sewer line (i.e., the fresher the sewage) the better the conditions. An average 8 hour retention time (or 16 miles distance) should not be exceeded. If problem areas exist, lines will have to be cleaned at shorter intervals. Air injection would be necessary if the sewage is transmitted in force mains for 1/2 hour or more to hold the dissolved oxygen concentration at about 0.5 mg/l.

Chlorine is often applied in a trunk line, pump station, or headworks of a treatment plant. It acts both to destroy any sulfide present and to prevent sulfide buildup in the chlorinated waste water for some time thereafter. The addition of a zinc salt to sewage containing sulfide generally reduces the dissolved sulfide concentrations to less than 0.1 mg/l. The formation of methane may be prevented by ventilation of the lines, since it takes only a very small amount of dissolved oxygen to kill methane-producing bacteria.

Long retention time in existing lines is a continuous problem because it leads to high concentrations of sulfides and hydrocarbons entering the treatment plant. If this is the case, everything should be carefully checked in the sewer system as discussed above, or the treatment plant itself would be an unsafe place to work and every area should be posted as a hazard area due to the presence of combustible and toxic gases. This will be discussed in the plant operation section of this manual.

A typical well-designed line is shown in Figure 3. There is no formation of H_2S, or CH_4 or bottom deposits because the liquid velocity is 3 ft/sec or greater. When a sewer line is in this condition there is little chance that problems will develop from anaerobic conditions.

A typical problem line is shown in Figure 4. This line is flowing at a velocity of less than 2 ft/sec. Anaerobic conditions have developed and have reached critical extremes, in part due to insufficient maintenance. The methane and sulfides could be a hazard to sewer line workers and treatment personnel. A spark in this sewer line or at the treatment plant when the sewage enters will cause an explosion. One solution to some of the problems is with oxygen aeration.

The condition in Figure 4 could be cured with oxygen. Figure 5 shows a simplified oxygen injection system. This type of system could improve six possible conditions:

1. Increase oxygen content in the sewer atmosphere
2. Remove H_2S (hydrogen sulfide) from the sewer before it changes to H_2SO_4 (sulfuric acid)
3. Dry exposed surfaces to prevent oxidation of H_2S
4. Eliminate toxic atmospheres
5. Remove explosive atmospheres

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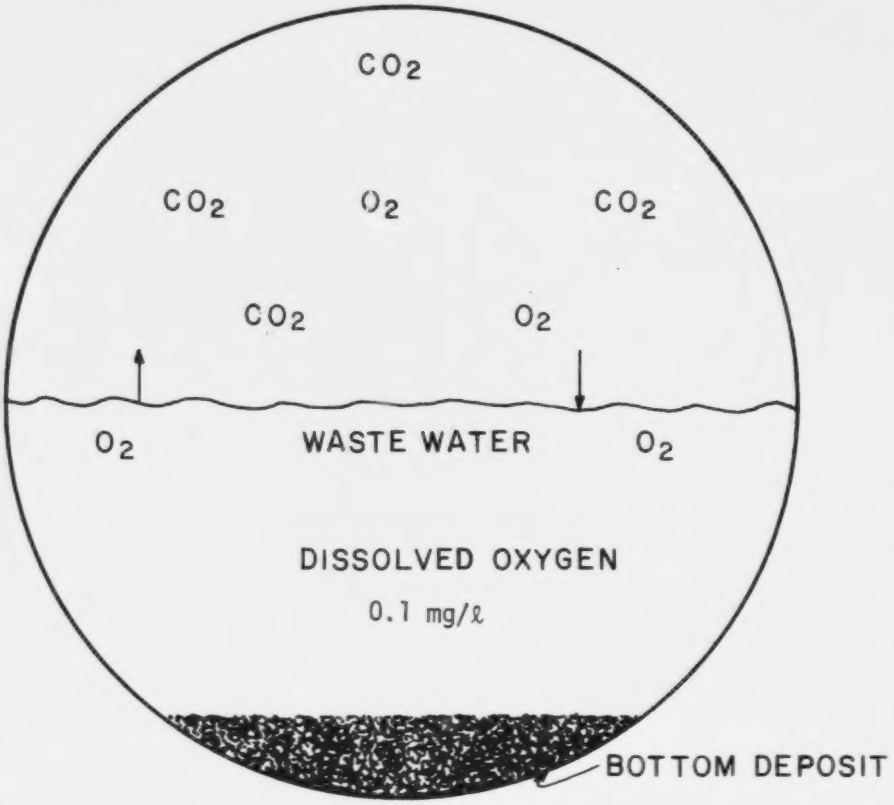
CO2
CO2
O2
CO2
CO2
O2
O2
WASTE WATER
O2
DISSOLVED OXYGEN
0.1 mg/ℓ
BOTTOM DEPOSIT

Figure 3. Sewer Line in Adequate Condition

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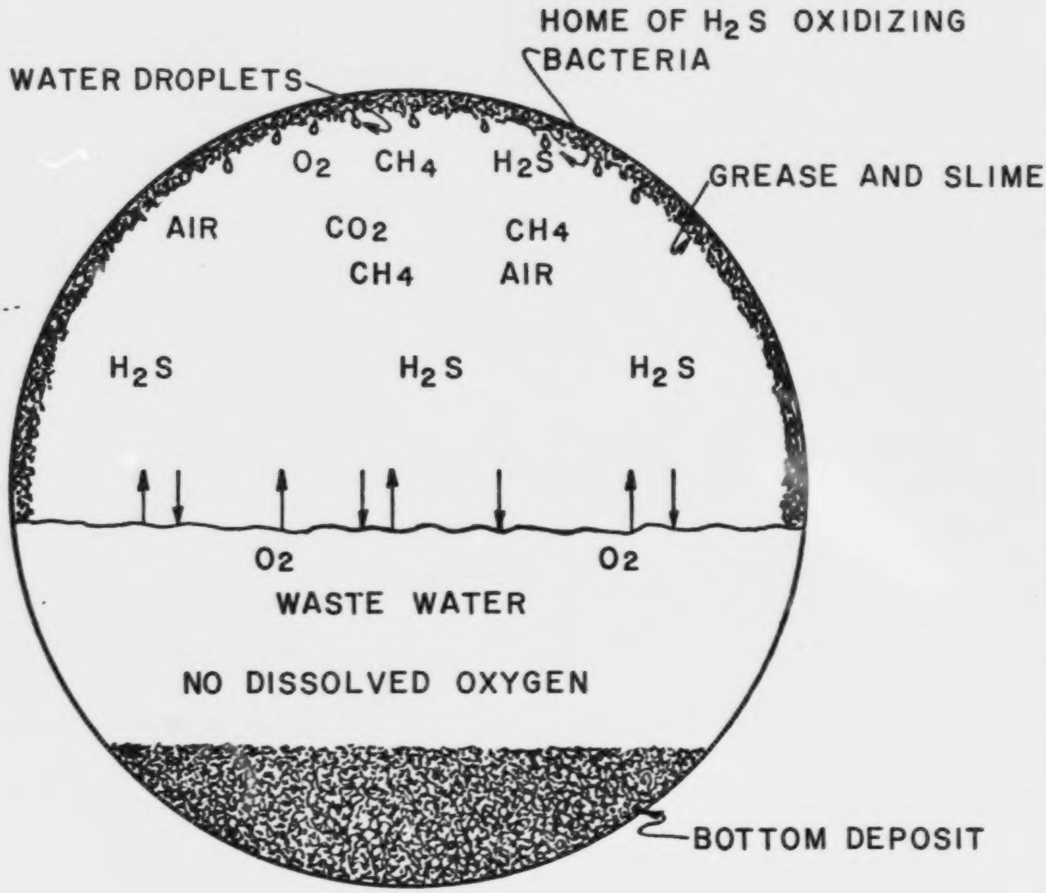
HOME OF H_2S OXIDIZING BACTERIA
WATER DROPLETS
O_2
CH_4
H_2S
GREASE AND SLIME
AIR
CO_2
CH_4
CH_4
AIR
H_2S
H_2S
H_2S
O_2
O_2
WASTE WATER
NO DISSOLVED OXYGEN
BOTTOM DEPOSIT

Figure 4. Sewer Line in Inadequate Condition

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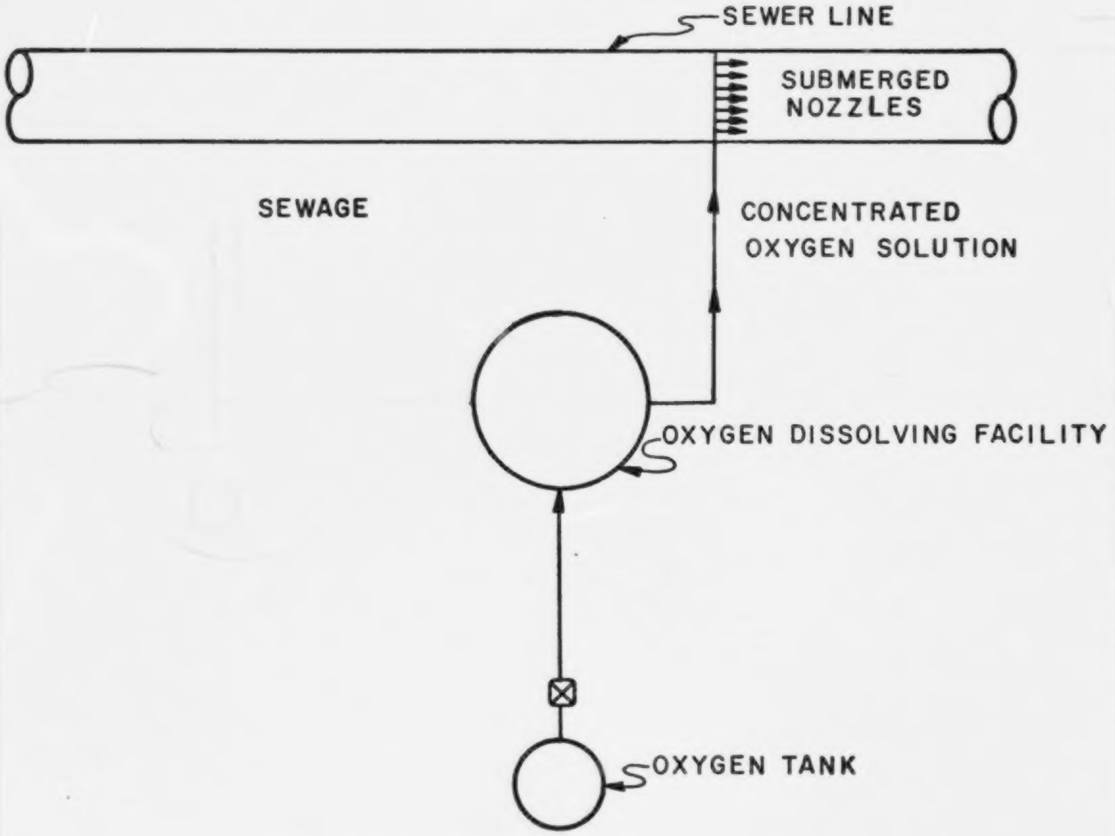

SEWER LINE
SUBMERGED NOZZLES
SEWAGE
CONCENTRATED OXYGEN SOLUTION
OXYGEN DISSOLVING FACILITY
OXYGEN TANK

Figure 5. In-Sewer Application of Oxygen

6. Control odors escaping from sewer line

E. COLLECTION SYSTEM MAINTENANCE

1. Frequency

The entire system should be inspected yearly. The frequency of inspection and the size of the maintenance department will depend on the size of the community and the size or complexity of the sewer system. It is not satisfactory to clean and repair sewers only when serious conditions develop. Such a policy is more costly than routine inspection and maintenance. Cleaning should take place every 3 to 5 years on a rotation basis.

Serious accidents have occurred over and over again associated with the inspection of sewers. Figure 6 illustrates the proper arrangement of personnel and warning equipment during inspection and work in the sewer.

In areas where explosive hazards, stoppages, or traffic damage are likely to occur, two or three inspections should be made each year. All inspections should follow a basic plan and procedure with respect to the conditions that should be observed. Cleaning should take place approximately every 3 years.

2. Flushing

Many communities do not permit automatic flushing devices anywhere in a sewer because of the possibility of contaminating the potable water supply through cross-connections. Other communities use flushing systems that utilize the sewage flow itself and have an arrangement to automatically discharge a given volume. When the normal flow of sewage is at a scouring velocity, there is a natural continuous flushing action, and deposits do not accumulate. These methods will help move the solids out of a slower area into an area that has a higher velocity so they may be carried to the treatment plant. Flushing by use of a fire hose is generally not effective because high velocities cannot be maintained for any considerable distance down the sewer.

3. Balling

This method works very well in removing inorganics, and organics from the bottom and sides of the sewer line. As the ball moves forward, it causes a high pressure stream of water to move around the ball and thus flush the accumulated debris ahead. The speed of the ball is controlled by an operator manning the attached upstream tag line. In larger lines a truck mounted winch is required to properly control the speed of the ball downstream. The debris moved by the ball can be removed by mechanical means at the first downstream manhole or carried along until a sufficient quantity is accumulated for removal. Under pressure, the ball distorts and allows a high-velocity stream of water to flow under it. At the same time, ribs built into the ball act as squeegees and remove the accumulated slimes, grease, etc. The ball is effective especially in the removal of organic buildup and heavy materials. In the case of stoppages, pulling on the tag line creates a jet of water which causes most stoppages to break loose.

1. OXYGEN METER ALARM SETTING AT 19.5 % OR LESS
2. SULFIDE METER ALARM SETTING AT 0.005 % OR MORE
3. COMBUSTIBLE METER ALARM SETTING AT 5% OR MORE

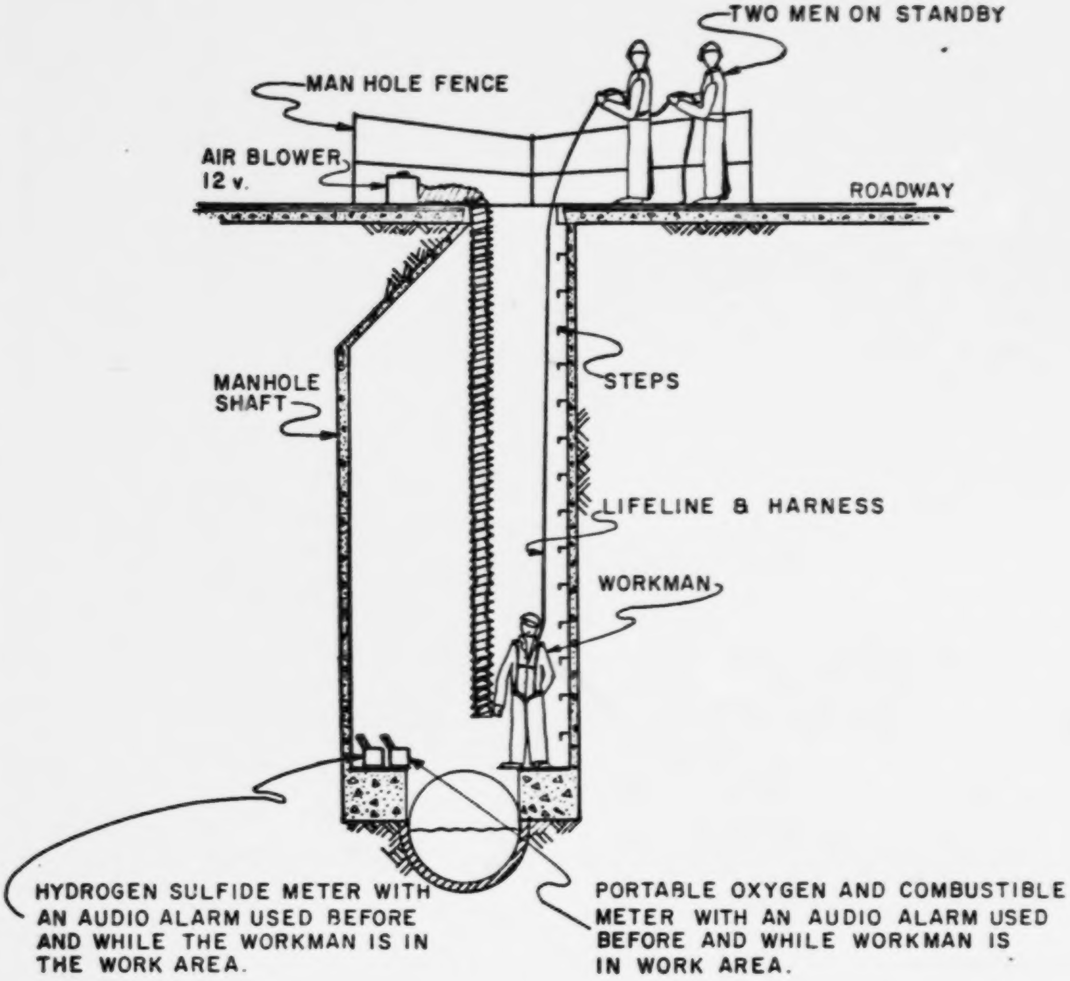

TWO MEN ON STANDBY
MAN HOLE FENCE
AIR BLOWER 12 v.
ROADWAY
MANHOLE SHAFT
STEPS
LIFELINE & HARNESS
WORKMAN
HYDROGEN SULFIDE METER WITH AN AUDIO ALARM USED BEFORE AND WHILE THE WORKMAN IS IN THE WORK AREA.
PORTABLE OXYGEN AND COMBUSTIBLE METER WITH AN AUDIO ALARM USED BEFORE AND WHILE WORKMAN IS IN WORK AREA.

Figure 6. Safe Work Practices in Sewer Systems

4. Hydrocleaning

This method which utilizes high pressure waterjets to scour organic buildup is effective in removing buildup in smaller sewer lines.

F. SAFETY CHECK LIST FOR COLLECTION SYSTEM

The following listed items are provided as a guide for collection system safety checks.

1. All known flat areas in the sewer system should be inspected frequently and atmospheres should be tested for the following:
    a. Explosive gases (methane, hydrocarbon vapors, solvents, etc.)
    b. Hydrogen sulfide
2. All suspected areas of possible flammable material discharges should be checked frequently for constituents listed in (1) above.
3. All trouble areas in which repeated sewer stoppages occur should be inspected and maintained frequently.
4. All sewage pump stations and wet wells should be inspected and maintained frequently to preclude production of constituents listed in (1) above.
5. All points in the sewer system where cesspool pumping trucks discharge should be inspected and maintained frequently to preclude entrance of flammable materials.

II. TREATMENT SYSTEM

The treatment system consists of the headworks, primary sedimentation tank, oxygen aeration actived sludge reactor, and secondary sedimentation tank, with the return activated sludge line. Any one of these subsystems may be of the open or closed tank type. A completely open-tank treatment system is diagrammed in Fig. 7, and a completely closed-tank system in Figure 8. In the latter case a recirculation blower is usually added to make the best possible use of oxygen in the reactor.

A. PLANT INFLUENT STATION WITH ENCLOSED HEADWORDS

1. Potential Hazards

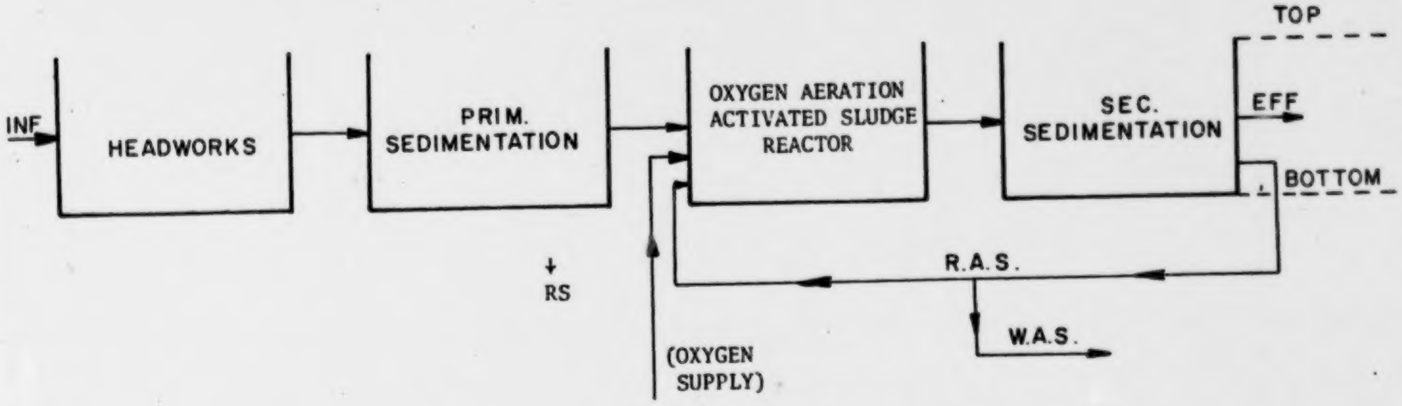
Any enclosed area is more of a hazard than an open area due to the concentrating effects of dangerous gases, especially if the ventilation system is not completely effective. If an operator puts his trust in ventilation alone, it could cost his life.

Hazards could be brought about by lack of oxygen in the headworks caused from high concentrations of combustibles such as sulfide and methane gases, which could enter at any time from the sewer line or develop from anaerobic conditions in the enclosed system. Figure 9 shows with an inadequate design, the problems that could develop, such as buildup of solids and grease in the wet well. Grease can build up on the walls of the wet well, turn anaerobic, and form septic conditions very quickly. In this design, too, the venting system is not adequate, so that incoming toxic or combustible gases and vapors of those which originate here never get flushed out. Any person who works under these conditions must always wear a self-contained oxygen mask.

The pumps themselves can form a hazardous condition if the packings are leaking sewage and not packing water. This small amount of sewage can form a considerable amount of sulfides and methane. If a pump bearing overheats, there could be a possible explosion inside the station.

The solids in the wet well design of Figure 9 are also a problem area. These solids will form anaerobic conditions below the surface and generate sulfides and methane. With such a headwork design the following should be done.

Chlorine should be introduced into the incoming sewage to neutralize and prevent sulfide or methane buildup. The wet well should be filled once a week and a strong solution of chlorine should be added to clean the walls. The wet well should be completely pumped out to remove floating grease. Also, the level in the wet well should be kept as low as possible without allowing


TOP
INF
HEADWORKS
PRIM.
SEDIMENTATION
OXYGEN AERATION
ACTIVATED SLUDGE
REACTOR
SEC.
SEDIMENTATION
EFF
BOTTOM
R.A.S.
W.A.S.
RS
(OXYGEN
SUPPLY)

INF = Influent
EFF = Effluent
RAS = Return Activated Sludge
WAS = Waste Activated Sludge
RS = Raw Sludge

Figure 7. Typical Treatment Plant-Open Tanks

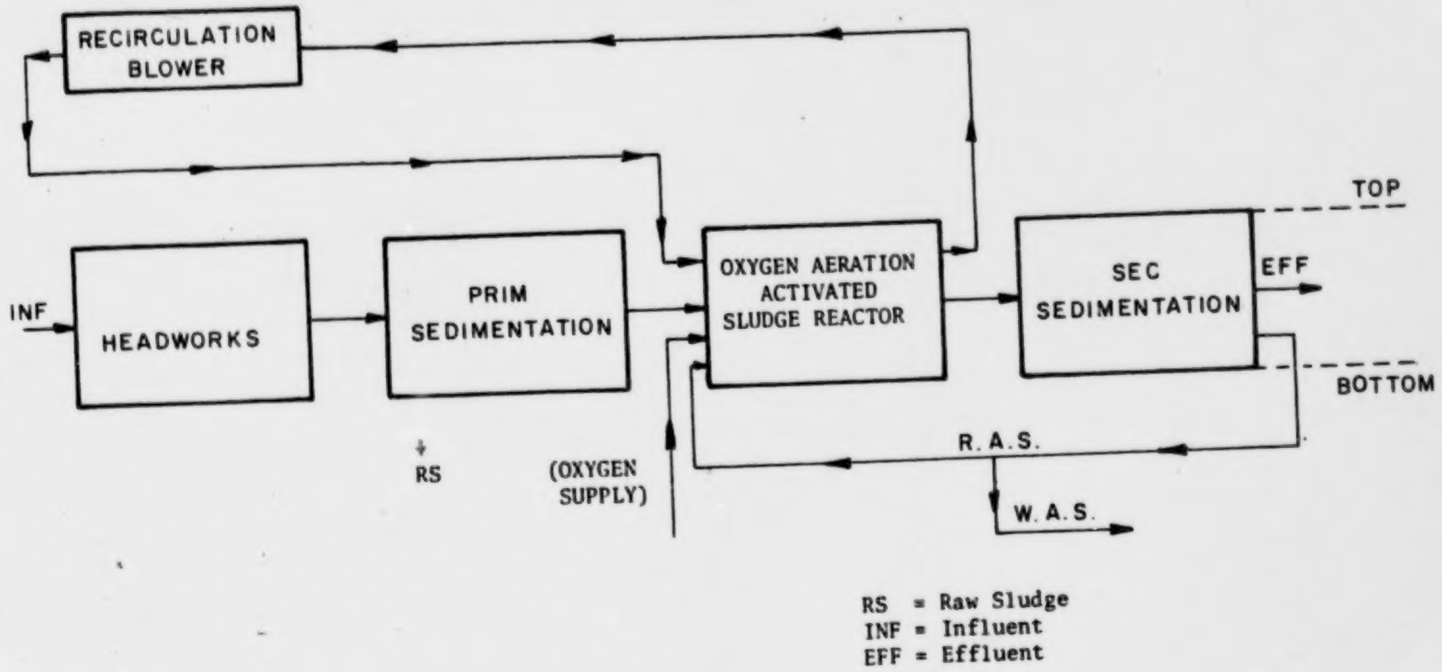

RECIRCULATION BLOWER
INF
HEADWORKS
PRIM SEDIMENTATION
OXYGEN AERATION ACTIVATED SLUDGE REACTOR
SEC SEDIMENTATION
TOP
EFF
BOTTOM
R. A. S.
W. A. S.
RS
(OXYGEN SUPPLY)
RS = Raw Sludge
INF = Influent
EFF = Effluent

Figure 8. Typical Treatment Plant-Closed Tanks

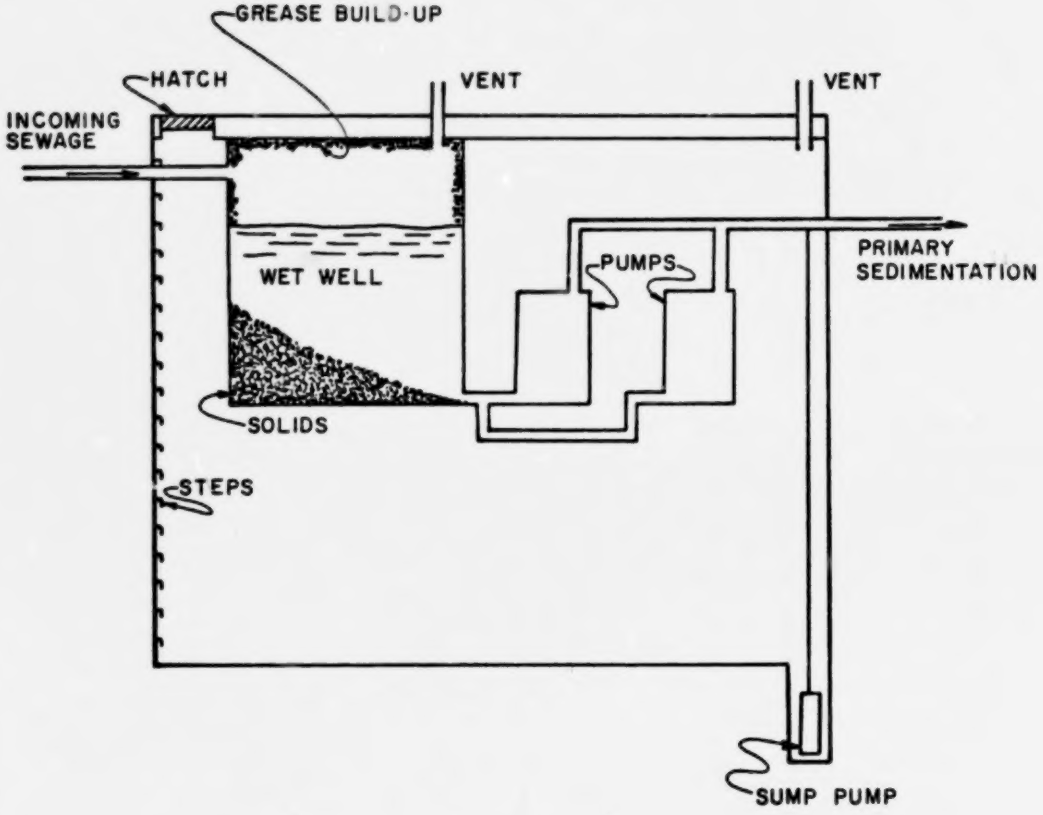

GREASE BUILD-UP
HATCH
VENT
VENT
INCOMING SEWAGE
PRIMARY SEDIMENTATION
PUMPS
WET WELL
SOLIDS
STEPS
SUMP PUMP

Figure 9. Enclosed Headworks-Inadequate Design

air to enter the pumps. If the pump does ingest air, it could pull the hazardous vapors out of the wet well and push them into the other treatment tanks. Once in an enclosed aeration tank with an oxygen-enriched atmosphere, these combustibles could form an explosive condition. If the sedimentation tank is enclosed, any combustible gases could be sucked into an overheated blower and explode. A well-ventilated headworks area could remove most of the incoming combustibles from industrial or domestic sources. If they enter an open aeration tank, they would be dissipated to the atmosphere.

Figure 10 shows an enclosed headworks with all the proper safety equipment. Ample fresh air ventilation is essential. The wet well should have a positive supply of fresh air furnished by a centrifugal blow discharging across the room. It should also have a suction exhaust fan located at a lower level. The blower should have sufficient capacity to provide a 2-minute air change (30 air changes per hour) based on the wet well volume below grade and above the minimum sewage level. Such blowers normally are operated only when the operators visit the station; hence, a large capacity is required only when the operators visit the station; hence, a large capacity is required to flush out accumulated stale air and gases quickly for the protection of the operators. Three-way control switches could be located just inside the door and in the room. As an extra protection, the blowers can be interlocked with the light switch or operated by a door switch. If the blower is equipped with a two-speed motor, it may be operated continuously at low speed, and at high speed only when personnel enter the station. All openings for pipes and electrical cables should be caulked and leak tight. The wet well and station should be washed down every day to prevent the buildup of grease on the walls. The atmosphere monitor should check for combustible gases, oxygen concentration, and sulfides before and while an operator is in the station.

There should never be a problem in the dry well area except possibly with poor pump packing maintenance. If a leak occurs in the exhaust system of the wet well, an explosive condition might develop if the wet well level gets too high, because the air blower will not function properly to evacuate the gases. This could be avoided with a high wet well alarm.

A liquid monitor should check for industrial combustibles such as hydrocarbons and dissolved sulfides. This indicates if a problem could develop in the wet well and also that combustibles are being discharged into the sewer line. This alarm will make an operator aware of the possible dangers to the plant. With the wet well design of Figure 10, there should not be any deposits on the bottom to develop sulfides or methane.

2. Wet Well Design

The wet well is seldom the site of substantial sulfide generation, even though it is often the place of odor release. The wet well can be used to aerate the wastewater. Since this is a technique that is difficult to apply in an existing system, the possibility should be considered when a new system is being designed.

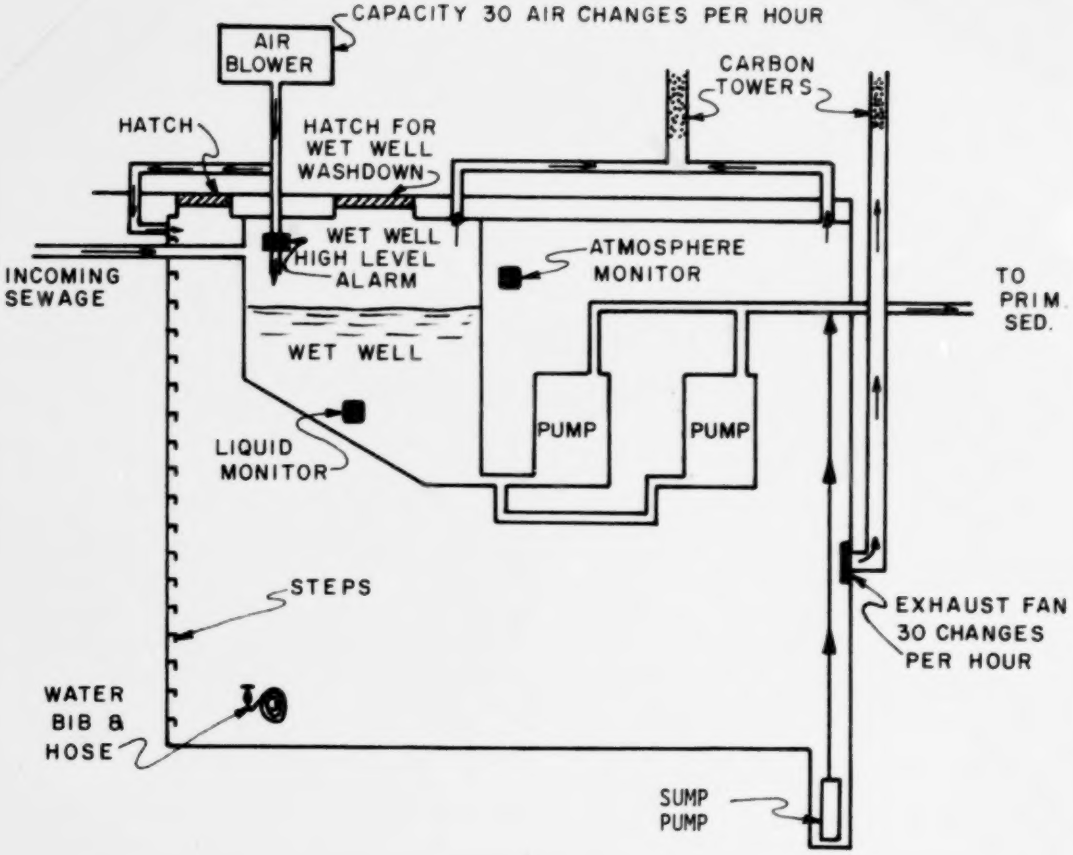

CAPACITY 30 AIR CHANGES PER HOUR
AIR BLOWER
CARBON TOWERS
HATCH
HATCH FOR WET WELL WASHDOWN
WET WELL HIGH LEVEL ALARM
ATMOSPHERE MONITOR
INCOMING SEWAGE
TO PRIM. SED.
WET WELL
PUMP
PUMP
LIQUID MONITOR
STEPS
EXHAUST FAN 30 CHANGES PER HOUR
WATER BIB & HOSE
SUMP PUMP

Figure 10. Enclosed Headworks-Adequate Design

The suction side of the pump should be located as close to the bottom of the wet well as possible. This way any of the solids that do settle out are washed out of the wet well into the pump as the sewage passes over it. The discharge and suction velocities of the pump should be in the range from 10 to 14 ft/sec. The end of the suction pipe in the wet well normally should be provided with either a 90- or 45-degree flange and flare elbows as shown in Figure 11. If D is the diameter of the flared inlet, then the lip of the flare at mid-height should be not less than 1/3 D nor more than 1/2 D above the floor. These types of wet wells should be used because of the self cleaning action that takes place in them. The type in Figure 12 should not be considered, because of the corner areas that can collect solids which turn septic to form sulfides and methane. The submergence required above a flare inlet in a well-designed wet well is approximately as follows:

Velocity at Diameter D, ft/sec	Required Submergence, feet
2	1
5	2
7	3
11	7
15	14

The floor of the wet well should be level from the wall to a point 12 to 18 inches beyond the outermost edge of the suction bell and should then slope upward to the opposite wall at a slope of approximately 2:1 (horizontal to vertical). The volume of the wet well between start and stop elevations for a single pump or a single control for variable speed or multispeed operation is given by

$$V = 0.25\ tQ$$

where

V = required capacity in gallons

t = minimum time of one pumping cycle, or time between successive starts or speed increases of a pump operating over the control range, minutes ($t \leq 20$ for large pumps and motors, $t \leq 10$ for smaller pumps and motors)

Q = pump capacity (gpm), or increment in the pumping capacity where the speed of the already operating pump is increased, or a second pump is started

3. Pumping Operations

Safe wet well pumping operations are very important. The wet well in Figure 13 is operating at too low a level, so that a vortex is formed at the pump suction side. In this condition, the pump no longer just pumps liquid, but also pulls in all of the vapors above the liquid level and pumps them throughout the system. With enclosed tanks, these vapors, if hazardous, can form

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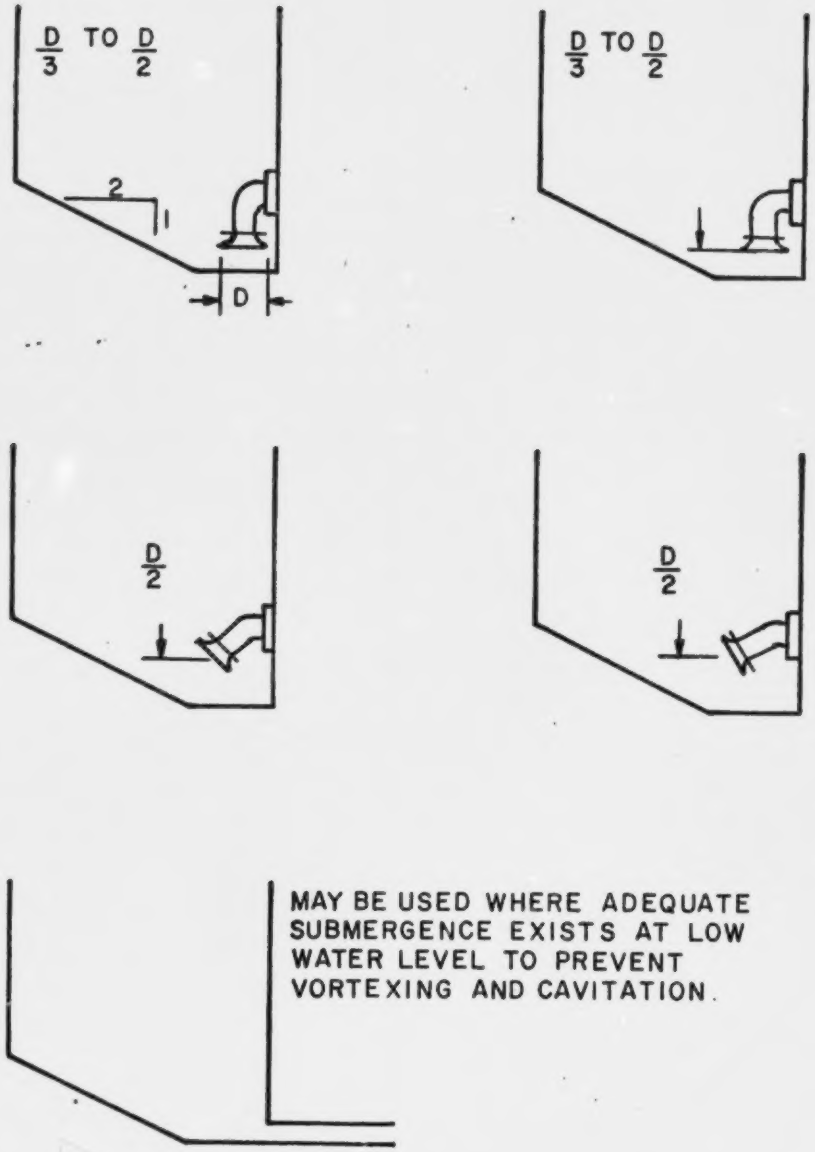

D/3 TO D/2
2
1
D
D/3 TO D/2
D/2
D/2

MAY BE USED WHERE ADEQUATE SUBMERGENCE EXISTS AT LOW WATER LEVEL TO PREVENT VORTEXING AND CAVITATION.

Figure 11. Acceptable Wet Well Designs

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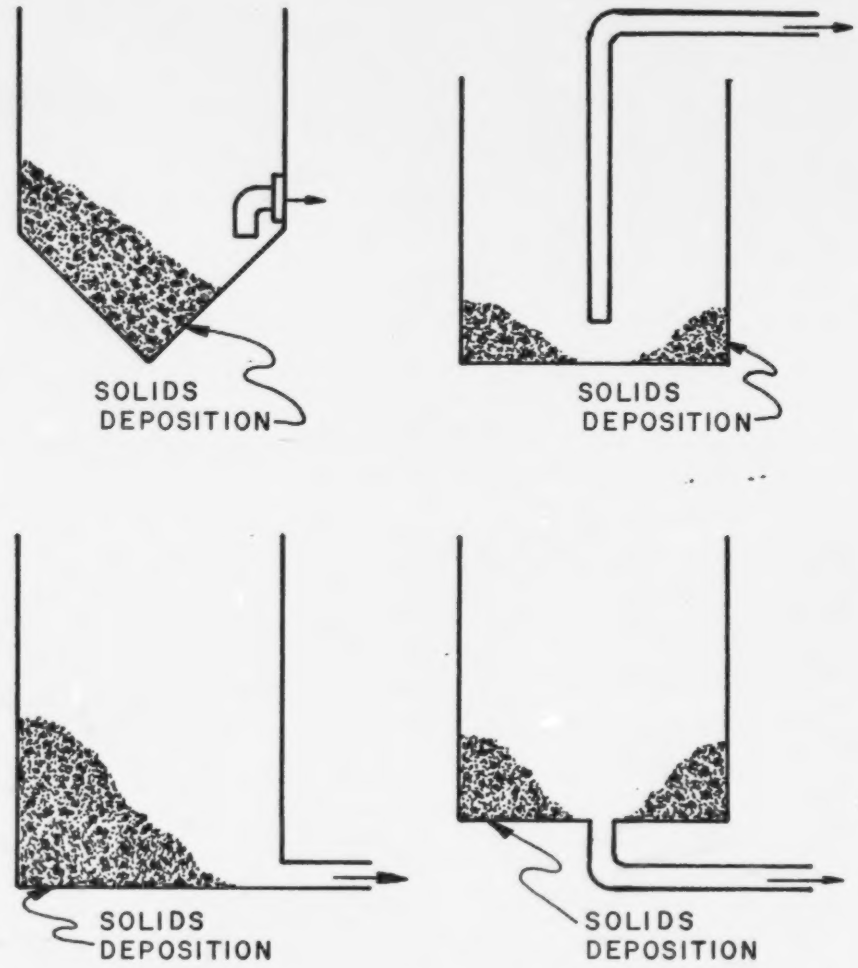
SOLIDS
DEPOSITION
SOLIDS
DEPOSITION
SOLIDS
DEPOSITION
SOLIDS
DEPOSITION

Figure 12. Non-Acceptable Wet Well Designs

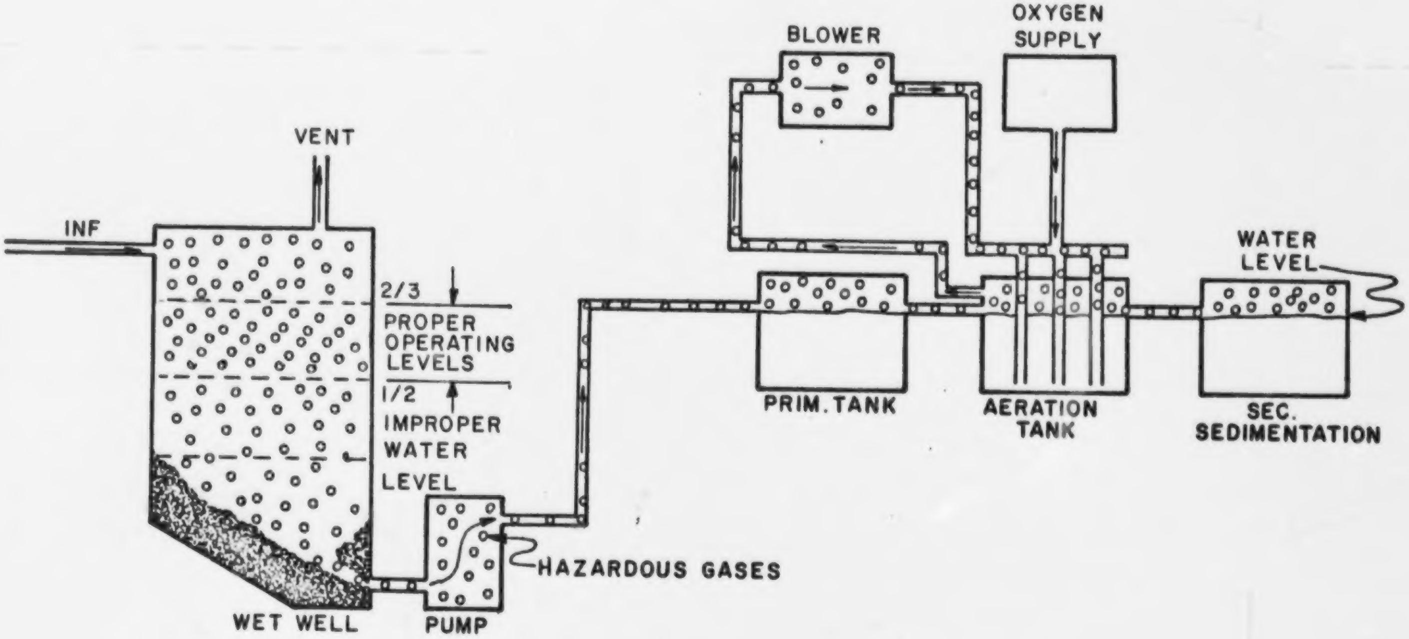
VENT
INF
2/3
PROPER OPERATING LEVELS
1/2
IMPROPER WATER LEVEL
WET WELL
PUMP
HAZARDOUS GASES
BLOWER
OXYGEN SUPPLY
PRIM. TANK
AERATION TANK
WATER LEVEL
SEC. SEDIMENTATION

Figure 13. Pump Cavitation Condition With Enclosed Tanks

explosive concentrations in the system. Even if the plant is being operated well otherwise, poor pump operations can cause very dangerous conditions. Dangerous vapors or liquids entering the plant from domestic or industrial sources could be retained in the plant effluent which would be very dangerous at the point of discharge.

The dotted lines in the wet well (Figure 13) show the proper levels between which the pump should be operated. With the wet well liquid surface between these levels, it would be impossible for the pump to pull the volatile vapors out of the well and push them throughout the plant. Of course, the primary effluent would not be the only hazardous area. An overheated blower or pump shaft could also cause an explosion in this system. The aeration tank could not be entered without a self-contained breathing mask. The enriched oxygen atmosphere increases the chances of supporting combustion in the aeration tank. This system, of course, should never be operated with oxygen enrichment, because the hazards will be greater.

If the solids as shown in Figure 12 are allowed to remain, they will turn anaerobic and form sulfides and methane. These vapors or gases would be transferred into the other parts of the enclosed treatment plant where they would be a hazard.

4. Station Venting

Venting is necessary to remove sulfides and methane from the headworks area which makes headworks safe and assists in preventing the remainder of the plant from receiving these gases. Forcing fresh air into the bottom and exhausting it at the top of the station as shown in Figure 14 keeps toxic and flammable conditions from developing.

5. Liquid Monitoring

The sewage should be analyzed for hydrocarbon content, which should include oil and grease analysis. If hydrocarbon analysis in the liquid phase is practical, a sampling program should be instituted to establish background levels of these constituents.

6. Atmosphere Monitoring

An enclosed headworks should have a sulfide monitor to warn an operator of toxic conditions before the area is entered. An operator could enter an area and possibly be overcome by the toxic effects of sulfides. The nose is not a good sulfide detector because small concentrations can paralyze the olfactory nerve and prevent their detection. A concentration of 0.1 percent by volume of sulfides in air is considered extremely toxic,* unless rescue is prompt, permanent brain damage results.

---

*Hydrogen sulfide is both an irritant and an asphyxiant. Low concentrations of from 20 to 150 ppm cause irritation of the eyes; slightly higher concentrations may cause irritation of the upper respiratory tract, and if exposure is prolonged, pulmonary edema may result. (Dangerous Properties of Industrial Materials, N. Sax, 4th Ed., 1975, Van Nostrand Reinhold, N.Y.)

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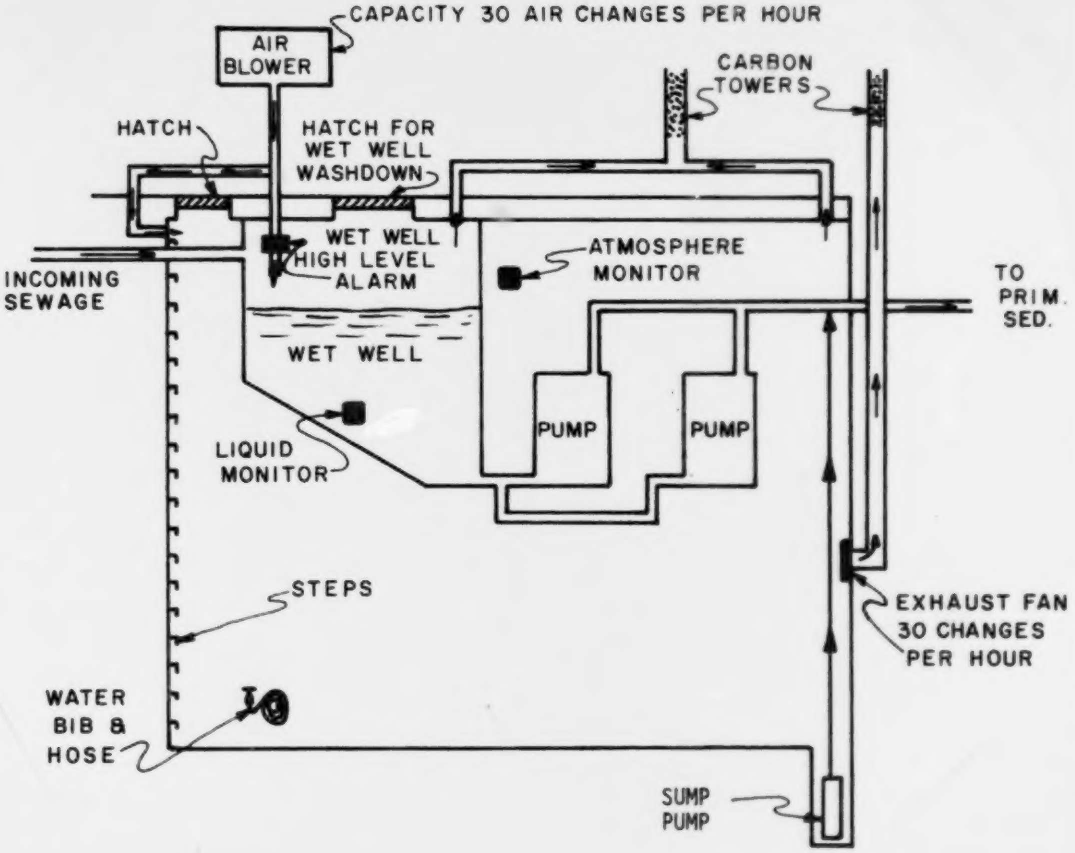
CAPACITY 30 AIR CHANGES PER HOUR
AIR BLOWER
CARBON TOWERS
HATCH
HATCH FOR WET WELL WASHDOWN
WET WELL HIGH LEVEL ALARM
ATMOSPHERE MONITOR
INCOMING SEWAGE
TO PRIM. SED.
WET WELL
PUMP
PUMP
LIQUID MONITOR
STEPS
EXHAUST FAN 30 CHANGES PER HOUR
WATER BIB & HOSE
SUMP PUMP

Figure 14. Enclosed Headworks-Adequate Design

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Methane monitoring is a must in an enclosed headworks because methane is odorless and explosive. With a methane monitor, an operator would be aware of the explosive condition before entering an area. A concentration of more than 5 percent by volume of methane in air is considered explosive.

Oxygen monitoring is also a must because the concentration could be lowered by the presence of sulfide or methane in the area. A reduction in the oxygen content of air below 20 percent by volume is considered unsafe.

7. Total Alarm System

A total alarm system would indicate the following conditions to the operator:

1. Sulfide--Toxic conditions exist in the enclosed headworks or conditions are being developed in this area.
2. Methane--Same as for sulfide but explosive instead of toxic.
3. Oxygen--There is a lack of oxygen and the operator will have to wear an oxygen mask before entering the station.
4. Wet Well--A low wet well level (as shown in Figure 13) will cause the pump to cavitate and pull the vapors out of the wet well and push them into the treatment plant where toxic or explosive conditions could develop. A pump should be operated at the level shown between the dashed lines in the drawing.

8. Treatment Equipment

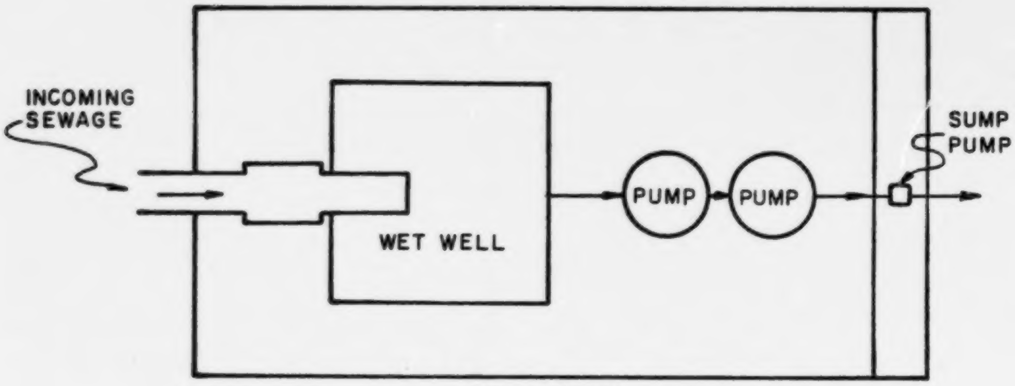
Treatment equipment should consist of the following and operate under prescribed conditions.

1. Main Pump--A high enough suction head should be maintained to prevent cavitation which results in methane and sulfide being pulled out of the wet well.
2. Sump Pump--All residual material should be dumped out of the headworks dry well area to the sedimentation tank. This material is that washed down in the station, such as sewage from the main pumps that leaked out of the packing gland or a leaky pipe or valve.

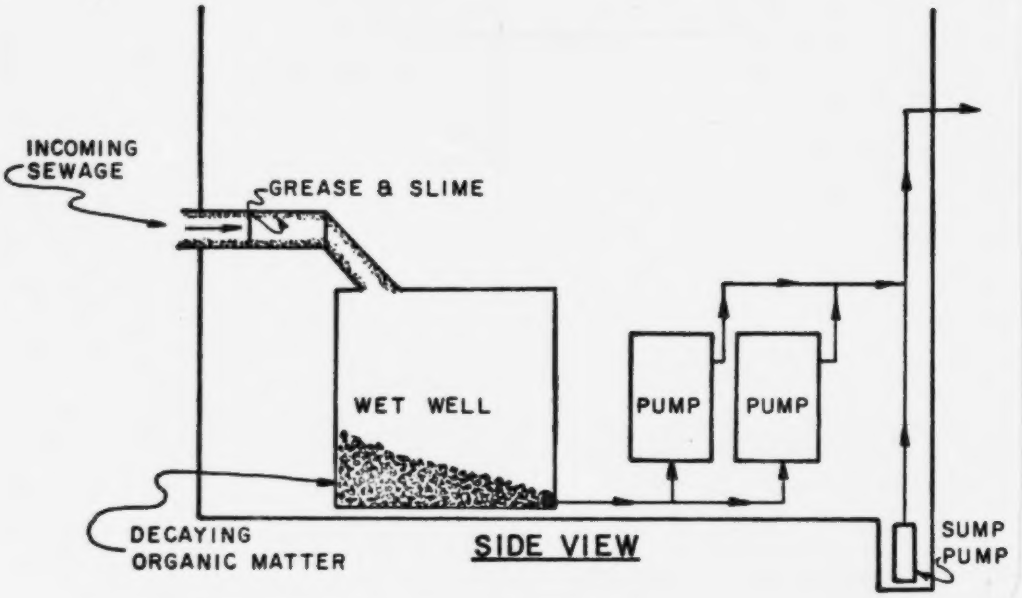
B. PLANT INFLUENT STATION WITH OPEN HEADWORKS

1. Potential Hazards

Any area in a treatment plant could be a hazardous area. Open headworks or any open unit process are safer than their enclosed counterparts as far as the concentration effects of dangerous gases are concerned. With an open channel, fresh air will always be entering it. Nevertheless, a problem could develop slowly, or an unexpected discharge could present an immediate hazard. If an industrial discharge does take place, the oxygen content in or near the bottom of the wet well could go well below the 0.5 mg/l limit stated in Section I,D,"Collection System Evaluation." Also, sulfide and methane gases could build up in the sewer and enter with the incoming sewage. An operator


INCOMING SEWAGE
WET WELL
PUMP
PUMP
SUMP PUMP

TOP VIEW


INCOMING SEWAGE
GREASE & SLIME
WET WELL
PUMP
PUMP
DECAYING ORGANIC MATTER
SUMP PUMP

SIDE VIEW

Figure 15. Open Headworks-Inadequate Design

working at a lower level could very easily be overcome by sulfides or an explosion could be caused by lighting a cigarette if combustibles enter that area.

As shown in Figure 15, grease can build up very quickly on the influent flow channel. Solids could also build up in the wet well and turn anaerobic. The sulfides and methane gas could build up and enter or fill the open work area with dangerous gases. With this type of system, one can at least be fairly sure that wind or air currents will help prevent heavy concentrations of gases.

Figure 16 shows an open headworks with all proper safety equipment. As in Figure 17, there should still be ample fresh air to keep high concentrations down. Cleaning the influent channel and wet well every day would remove most suspected problems, but no matter how clean they are kept, one should remember that an unexpected industrial discharge could enter the system at any time. Continuous monitoring alarm systems make it unnecessary to enter the headworks to determine if there are any problems at the lower levels. The monitoring devices should check for oxygen content or for combustibles or sulfides that may be in the atmosphere. The liquid monitor should also check for hydrocarbons or dissolved sulfides. With this type of wet well design there should not be a deposit problem.

2. Pumping Operations

Proper wet well operation is very important. In Figure 17 the wet well is being operated at the proper levels. Even if it were not, and the pump were cavitating, the gases would be vented off through the open tanks into the atmosphere as shown by the arrows. However, even though the tanks are open, there could be an explosive mixture coming off at some time due to a volatile gas from a domestic or industrial source. A volatile liquid that is explosive could also come in and be carried throughout the plant.

3. Liquid Monitoring

The sewage should be analyzed for hydrocarbon content, which should include oil and grease analysis. If hydrocarbon analysis in the liquid phase is practical, a sampling program should be instituted to establish background levels of these constituents.

4. Total Alarm System

A total alarm system would indicate the following conditions to the operator:

1. Sulfide--Toxic conditions exist in the open headworks or conditions are being developed in this area.
2. Methane--Same as for sulfide, but explosive instead of toxic.
3. Oxygen--There is a lack of oxygen and the operator will have to wear an oxygen mask before entering the station.

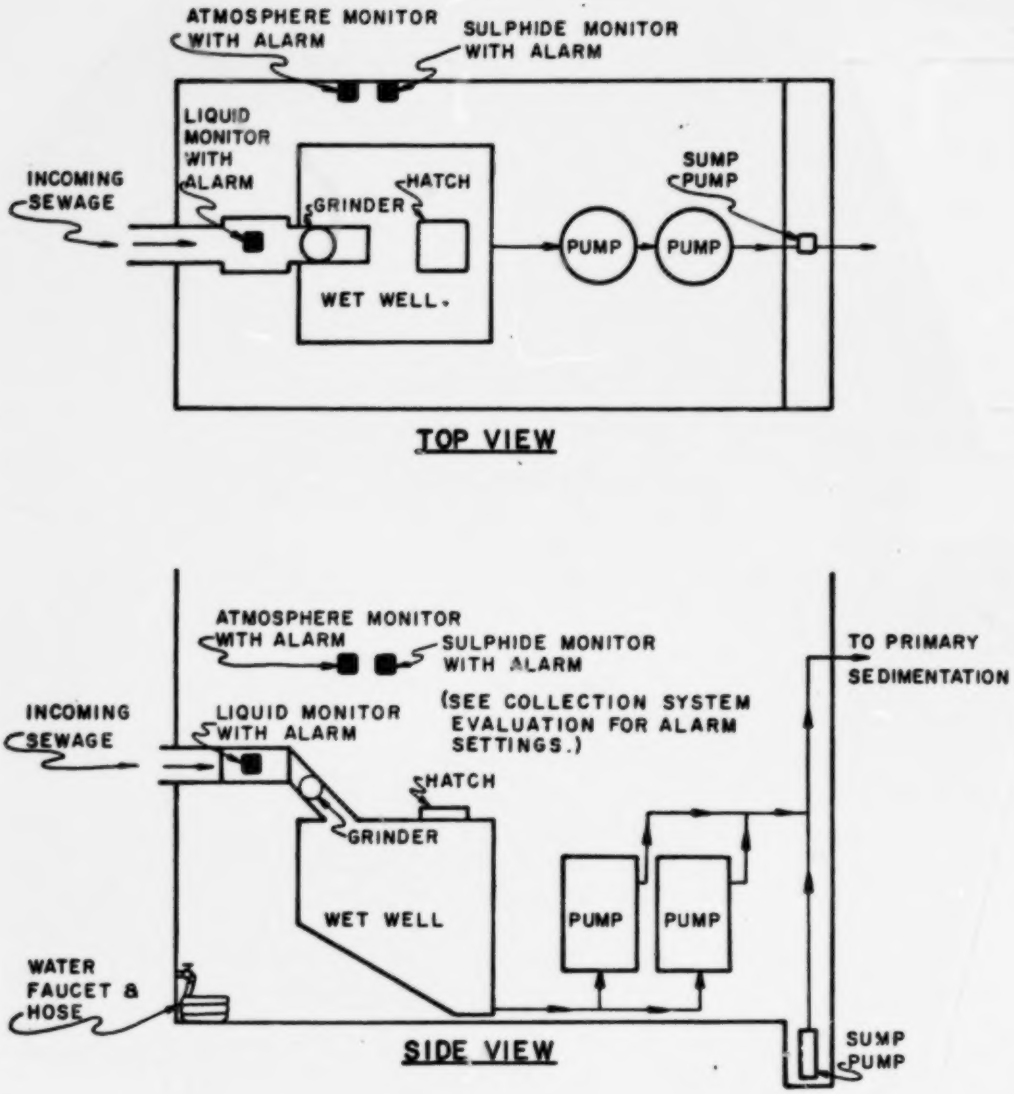

ATMOSPHERE MONITOR WITH ALARM
SULPHIDE MONITOR WITH ALARM
LIQUID MONITOR WITH ALARM
INCOMING SEWAGE
GRINDER
HATCH
SUMP PUMP
PUMP
PUMP
WET WELL.
TOP VIEW
ATMOSPHERE MONITOR WITH ALARM
SULPHIDE MONITOR WITH ALARM
(SEE COLLECTION SYSTEM EVALUATION FOR ALARM SETTINGS.)
TO PRIMARY SEDIMENTATION
INCOMING SEWAGE
LIQUID MONITOR WITH ALARM
HATCH
GRINDER
WET WELL
PUMP
PUMP
WATER FAUCET & HOSE
SIDE VIEW
SUMP PUMP

Figure 16. Open Headworks-Proper Design

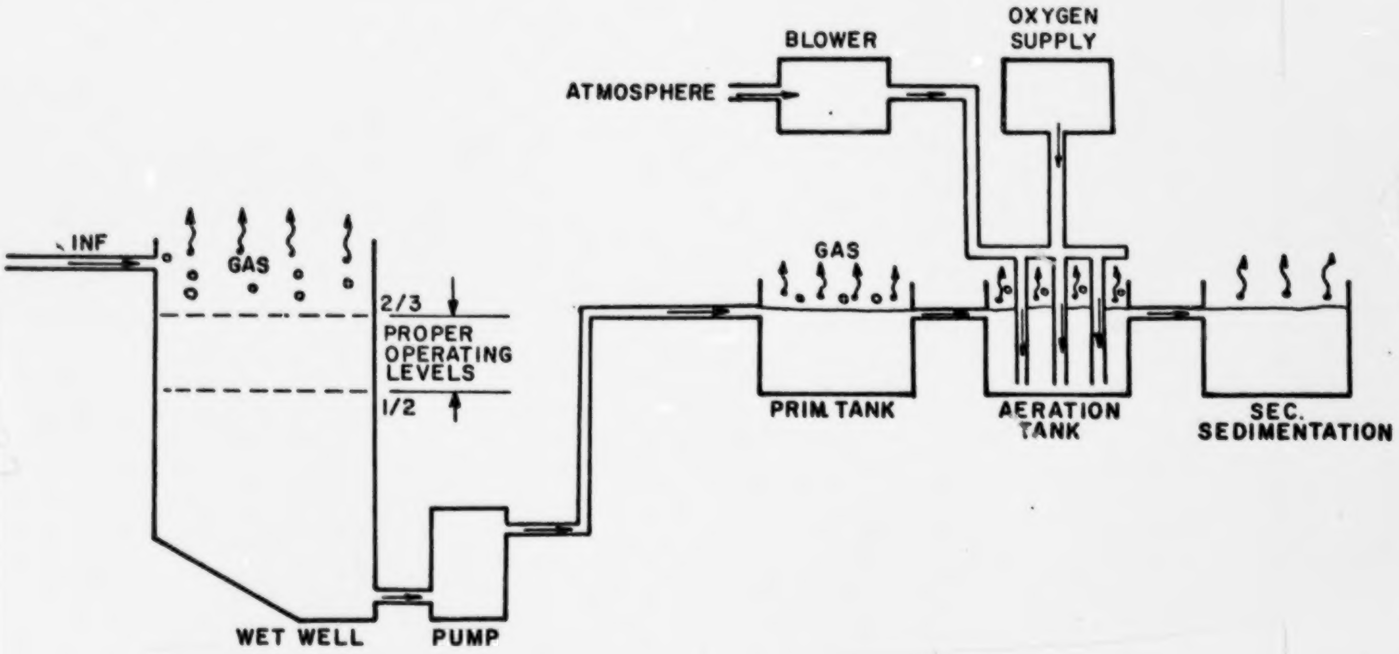

ATMOSPHERE
BLOWER
OXYGEN SUPPLY
INF
GAS
2/3
PROPER OPERATING LEVELS
1/2
GAS
WET WELL
PUMP
PRIM. TANK
AERATION TANK
SEC. SEDIMENTATION

Figure 17. Proper Pumping Conditions With Open Tanks

4. Wet Well--A low wet well level will cause the pump to cavitate and pull the vapors out of the wet well and push them into the treatment plant where toxic or explosive conditions could develop. A pump should be operated at the level shown between the dashed lines in Figure 17.

5. Treatment Equipment

The following equipment is needed.

1. Main pumps--To pump the sewage out of the open wet well

2. Sump Pump--To keep the wet well area clean

C. SAFETY CHECK LIST FOR PLANT INFLUENT STATION

The following listed items are for safety check of a plant influent system.

1. Wash down the wet well walls routinely to remove any grease or slime that could lead to buildup of sulfides and methane.

2. Make sure that solids do not build up in the wet well. If they do, they will turn anaerobic and form methane and sulfides which can then be transferred to the sedimentation tank and form toxic and explosive conditions.

3. Make sure that the pump is operating the wet well in a range of about 1/2 to 2/3 full. In this way, the pump will not be able to suck any of the combustible or toxic vapors out of the well and force them into other parts of the treatment plant.

4. Check the operation of all ventilating fans to ensure that the headworks area is being properly exhausted of toxic and/or combustible gases.

5. If there are two pumps on the wet well, alternate them each week. In this way solids that build up next to an inactive pump will be removed when that pump is started. This will prevent the solids from turning anaerobic and forming methane and sulfides.

6. Make sure that the pump packing and packing water are properly adjusted so as to not let sewage leak out of the packing gland onto the floor where it could turn anaerobic and form methane and sulfides. The pump packing water should be set at 10 psi, or higher than the discharge pressure on the pumps.

7. Check that all safety equipment is operating properly. The sulfide, methane and oxygen monitors indicate to the operator when conditions are unsafe in the headworks area and indicate what hazardous matter may be entering the plant. If the oxygen content is less than 20 percent, the operator will have to wear a self-contained oxygen mask before entering the area. If an explosive mixture is indicated, operators in other parts of the plant should be made aware of the explosive hazards which might also occur in other parts of the plant.

8. The influent flow should be checked. If it is higher than usual, it will be necessary to make certain that the oxygen demand in the aeration tank is met.

D. PRIMARY SEDIMENTATION-RECTANGULAR ENCLOSED TANK

1. Potential Hazards

Sulfide and methane could enter this tank because of poor sewer cleaning procedures or from a poorly operated enclosed headworks. If solids are being deposited or volatile liquids spilled in the sewer lines, anaerboic conditions could develop and sulfides and methane could be generated and enter the headworks. Even if the headworks area is kept clean, improper pump operations could pull the gases from the wet well and push them into the sedimentation tank where toxic or explosive conditions could arise.

To prevent these conditions, operate the pumps as described in the "Total Alarm" paragraphs of the open Headworks Section 11,B4. If the headworks are well maintained and properly ventilated, problems still can develop in the sedimentation tank. If the settleable solids are permitted to stay in the tank longer than the usual 3 to 4 hours because of overloading or underpumping, or some other condition, anaerobic conditions could develop and these could form methane and sulfides. These gases would be dangerous under this cover and also in the aeration or secondary sedimentation tanks. Operators around any of these areas could be overcome by the toxic sulfides or a methane explosion could occur by improperly operating equipment in which the temperature could become high enough to cause combustion. Sparking tools and open motors should be avoided because arcing or sparks created by hand or power tools could ignite gases.

The tank is equipped with sludge collection equipment, chains, flights, and drive motors. If a chain breaks, or a drive motor stops, the flights will not pull back the sludge that settles out in the tank. This sludge will turn anaerobic very quickly and form methane and sulfides in the tank. These gases will be carried with the effluent to the other treatment processes where they would be toxic or explosive.

The operator should know how much settleable solids are received into the plant each day. The pumping scheme should be set up to pump out the proper amount of sludge daily. The sludge blanket should be kept to about 1/3 of the side wall depth during peak flows, as shown in Figure 18 which indicates a well operated tank. The operator could check the sludge blanket depth with a depth finder or other means. If the tank is operated well there will only be a slight odor under the cover. There should be no signs of black clumps of sludge on the surface as shown in Figure 19. The grease skimmer should be operated once each day at the low flow period to remove all floating grease. The skimmer and trough should be washed down each day so that decomposition does not occur. The flights and drives should be checked each day to ensure that none are broken. An alarm system should be tied into the flight mechanism, in case the latter malfunctions and stops. An operator should check the sludge pumping rates each day to make certain that the right amount of sludge is pumped. This check should be based on some type of flow meter and not on the pump motor readings, because the motor may be running but the pump may not be pumping. The atmosphere alarm is a must, because problems could develop very easily in the presence of such a large quantity of sludge which is at zero dissolved oxygen. The liquid monitor is also very important because the sludge may be satisfactory but unexpectedly some type of combustible could be discharged into the system. The alarms detect this type of problem, even with good operation. Refer to the Collection System Evaluation, Section II,A6, for alarm settings.

The properties of sludge vary according to conditions. When the raw sludge comes into the primary sedimentation tank, its dissolved oxygen is zero. If the sludge stays in the primary tank too long, bacteria starts decomposing it and forms carbon dioxide, hydrogen sulfide, and methane gas. The carbon dioxide is not explosive, but it will get into the sludge particles and the clumps of black sludge will float to the surface of the tank. This is shown in Figure 19 which is similar to Figure 18 except that some equipment is not shown. When a tank gets into this condition, sulfides and methane will form very quickly and cause immediate hazards.

Listed below are various conditions that will cause rising or septic sludge:

1. Broken flights, chain, or drive motor result in no collection of sludge
2. Sludge pumping rate is too low
3. Surface loading is too high: in excess of 1000 $gal/ft^2/day$
4. Detection time is too long: in excess of 3 hours

The methane gas caused by anaerobic conditions (indicated by the rising septic sludge) could ignite and cause an explosion. The suction side of the blower is sucking in the tank atmosphere (Figure 13). A blower may get hot enough to cause an explosion within it. Any methane will then be pushed up to the aeration tank where an oxygen-enriched atmosphere could lead to a combustion problem. Any sulfides could cause a serious toxicity problem to anyone working in these areas.

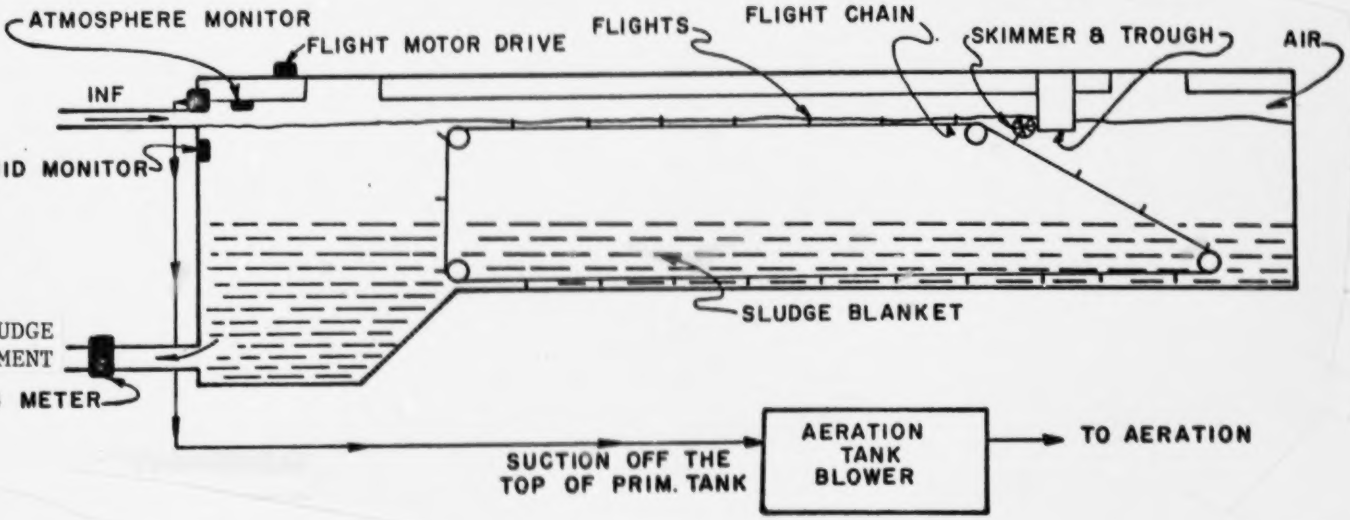

ATMOSPHERE MONITOR
FLIGHT MOTOR DRIVE
FLIGHTS
FLIGHT CHAIN
SKIMMER & TROUGH
AIR
INF
LIQUID MONITOR
SLUDGE BLANKET
TO SLUDGE TREATMENT
MAG METER
SUCTION OFF THE TOP OF PRIM. TANK
AERATION TANK BLOWER
TO AERATION

Figure 18. Rectangular Enclosed Primary Sedimentation Tank

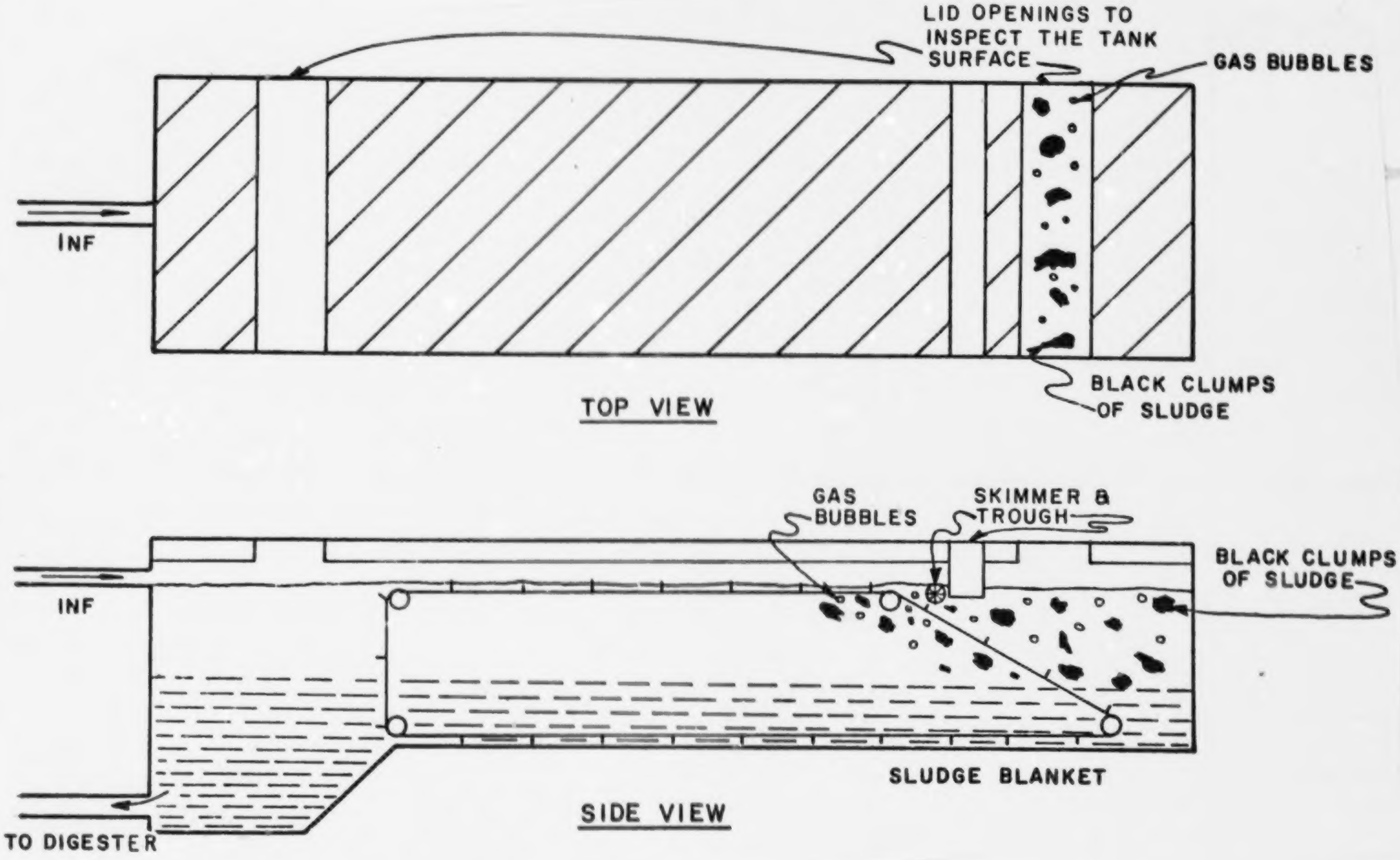

LID OPENINGS TO INSPECT THE TANK SURFACE
GAS BUBBLES
INF
BLACK CLUMPS OF SLUDGE
TOP VIEW
GAS BUBBLES
SKIMMER & TROUGH
BLACK CLUMPS OF SLUDGE
INF
SLUDGE BLANKET
TO DIGESTER
SIDE VIEW

Figure 19. Rectangular Enclosed Primary Sedimentation Tank - Showing Signs of Sludge Decomposition

2. Vented Configurations

If the blower is pulling the vapors off the top of the sedimentation tank and pushing them into the aeration tanks, any problems would be moved from one tank to another. If for some reason the blower is overheated because of running it near or in a surge condition, any methane could explode inside the blower. Therefore, the blower should always operate in the proper range as called for by the discharge gauge. Of course, with an oxygen enriched environment in the enclosed aeration tank the problem is magnified because if there are any leaks in the cover, an operator could easily ignite the methane. Even with an open aeration tank these vapors are pushed up through the liquid into the atmosphere where they could be ignited, since methane gas is practically insoluble in water. If the tank is vented to the atmosphere, gases could be released all around the sedimentation tank where they could be toxic or explosive.

3. Liquid Monitoring

Analysis for hydrocarbons is needed to detect petroleum products such as solvents and oils that may have gotten past the headworks.

4. Atmospheric Monitoring

Sulfides or methane could be forced into the tank from the headwork area by improper conditions. These gases could enter with the sewage or be produced in the wet well. If their levels are satisfactory in the headworks area, but not in the sedimentation tank, the operator should realize immediately that the sedimentation tank is not being operated properly. An enclosed tank should have a sulfide monitor in it to warn the operator of toxic conditions before entering the area to avoid being overcome by toxic gases. Sulfides should be below the toxicity level of 0.001 percent in air by volume. Your nose cannot be relied upon for sulfide detection because small concentrations can paralyze the olfactory nerve and prevent sulfide detection. Methane monitoring is also a must in an enclosed tank because methane is odorless and explosive. In this way, the operator would be made aware of explosive conditions before entering the area. Methane should be below the explosive level of 5 percent in air by volume. Oxygen monitoring is also a must, especially if a worker has to enter a tank for repair work. An oxygen mask should be used if the oxygen content is less than 20 percent.

5. Total Alarm System

The following are conditions and results which a total alarm system can detect and aid to control:

1. Methane--Explosive in that area and can possibly be pushed into other areas where it could be explosive.

2. Sulfides--Toxic in that area and can possibly be pushed into other areas where they could be toxic or explosive.

3. Oxygen--May fall below an acceptible concentration in air, when an operator must be alerted to wear an oxygen mask before entering the tank.

4. Sludge Collection Equipment--Any malfunction must be detected to let an operator know immediately if the removal of sludge has been affected, so that the problem can be corrected before anaerobic conditions develop.

These alarms are to notify the operator of a malfunction or dangerous condition so that proper corrective actions may be taken.

6. Treatment Equipment

The treatment equipment consists of the following:

1. Sludge Collection Equipment
2. Flights; Chains; Drive Motors
3. Sludge Pumps (for sludge removal)
4. Grease Skimmer and Drive Motor
5. Explosion-proof motors and anti-sparking tools

E. PRIMARY SEDIMENTATION-RECTANGULAR OPEN TANK

1. Potential Hazards

An open tank is safer than a closed tank because concentrated gases can not develop as easily. Most primary tanks have a freeboard of about 2 feet. Atmospheric monitoring is not essential due to the open tank top and small area of freeboard. The wind currents could help keep the tank atmosphere area pretty well swept. Two problems that create hazards in the enclosed tank, however, also hold true for the open tank. Methane and sulfides could still form, but the concentrations would be small.

The detection time should be the same as for the enclosed tank. All operating procedures for this tank are the same as for the Primary Sedimentation-Rectangular Enclosed Tank, Section II,D. An advantage in operating this type of tank lies in the ability of always being able to check the surface. The operator should look for large quantities of gas bubbles rising to the surface. This would indicate the possibility of sludge rising next, with formation of sulfides and methane.

Figure 20 illustrates such a condition. Gas bubbles have caused sludge to rise to the surface. This is indicative of several problems.

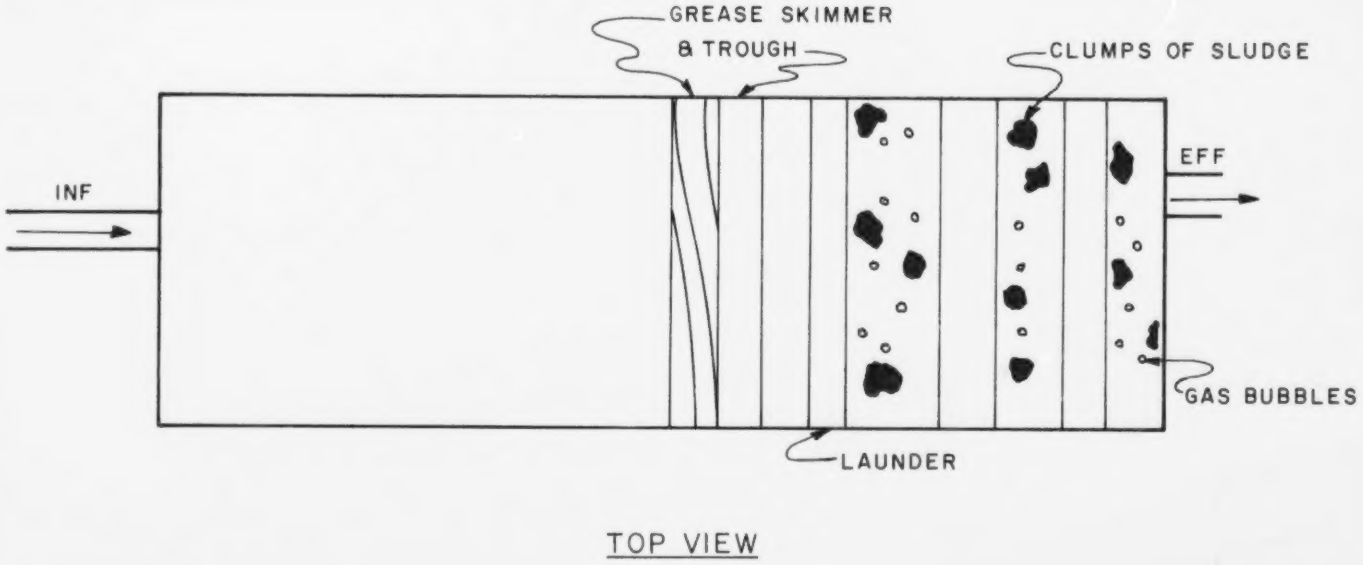

GREASE SKIMMER
& TROUGH
CLUMPS OF SLUDGE
EFF
INF
GAS BUBBLES
LAUNDER
TOP VIEW

Figure 20. Open Rectangular Primary Sedimentation Tank-Inadequate Operation

1. Not enough sludge pumped

2. Sludge collection equipment turned off

3. Sludge collection equipment malfunction

2. Total Alarm System

a. Liquid Monitoring - Analysis of hydrocarbons is necessary. Methane produced by poor design or operation, as discussed above, could be transferred to the aeration reactor.

b. Sludge Collection Equipment Failure Alarm - The failure alarm will indicate to the operator immediately if the removal of sludge has been affected so that the problem can be corrected before anaerobic conditions develop and methane is formed.

3. Treatment Equipment

Sludge collection equipment, includes flights, chains, and drive motors, sludge pumps, and a grease skimmer and drive motor.

Only explosive-proof motors and anti-sparking tools should be used in these areas.

F. PRIMARY SEDIMENTATION - CIRCULAR ENCLOSED TANK

1. Potential Hazards

Sulfides and methane could enter this tank because of poor sewer cleaning procedures or from a poorly operated enclosed headworks. If solids are being deposited in the sewer lines, anaerobic conditions could develop, and sulfides and methane could be generated and enter the headworks. Even if the headworks area is kept clea[illegible]oper pump operations could pull the gases out of the wet well and pus[illegible] into the sedimentation tank where toxic or explosive conditions could arise. To prevent this from happening, operate the pump as described in Pumping Operations II, A, 3 in the Enclosed Headworks section.

In a closed tank, serious problems could develop undetected because one cannot see what is going on within the tank at all times, especially if the atmosphere above the liquid level is not vented. Methane and sulfide could form very easily in any primary tank because the dissolved oxygen content is usually zero, and concentrations could build up to very heavy explosive mixtures. The average detention time in a primary tank is about 2 hours. An operator should determine the pounds of settleable solids received by the plant each day, and set up a pumping scheme to pump that daily amount out of the primary tank. The sludge blanket should be kept down to 1/3 of the sidewall depth during peak flows. This is done in Figure 21 which shows a well-operated tank with monitors in the liquid and in the atmosphere above the

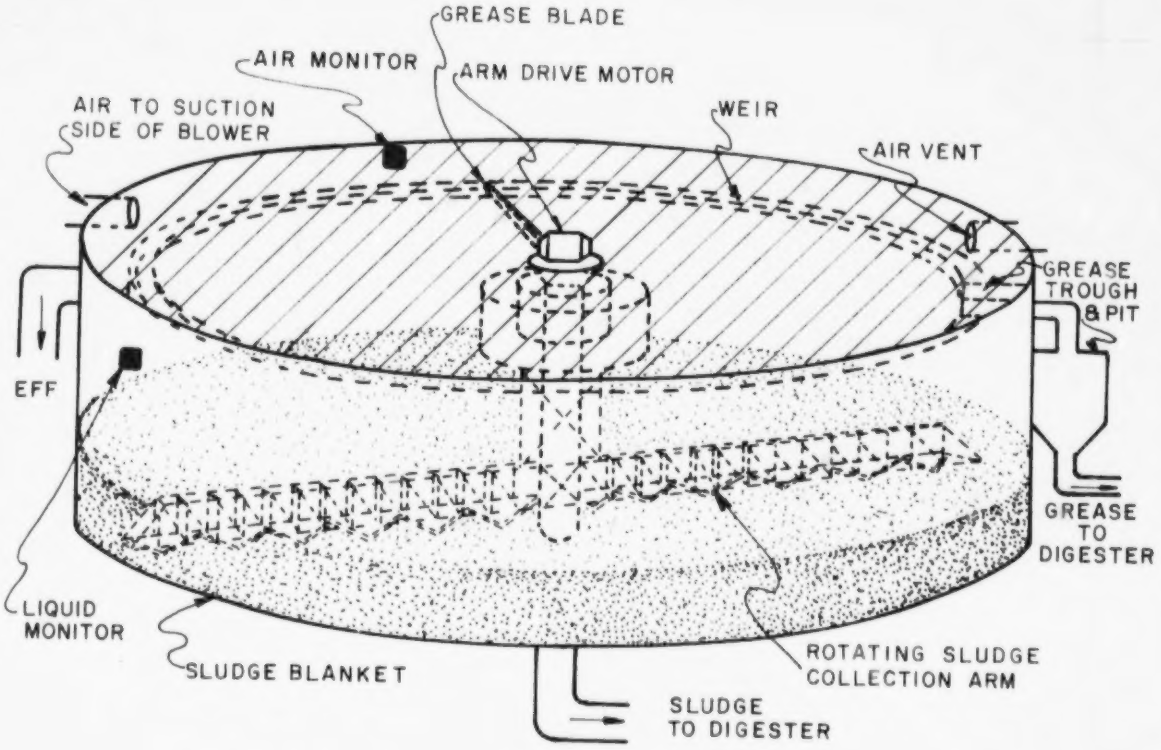

GREASE BLADE
AIR MONITOR
ARM DRIVE MOTOR
AIR TO SUCTION SIDE OF BLOWER
WEIR
AIR VENT
GREASE TROUGH & PIT
EFF
GREASE TO DIGESTER
LIQUID MONITOR
SLUDGE BLANKET
ROTATING SLUDGE COLLECTION ARM
SLUDGE TO DIGESTER

Figure 21. Enclosed Circular Primary Sedimentation Tank-Adequate Operation Condition

liquid. An operator could check the depth with a depth finder or other means. If the tank is operated well there will only be a slight odor under the cover.

In a poorly operated tank, black clumps of septic (anaerobic) sludge rise to the surface as shown in Figure 22, which is the same tank as shown in Figure 21, but with some of the equipment omitted. The grease skimmer in this tank (Figure 21) is operated all the time as long as the sludge collection arm is rotating. The trough should lead to a grease pit outside the tank. When the pit reaches a certain level the sludge should be either pumped to the digester, hauled to a landfill, or otherwise disposed of. The trough and pit should be washed down at the end of each grease removal cycle. In this way there will not be any sulfide or methane buildup in the grease trough or pit. The rotating arm should be checked each day to make sure that it did not stop rotating or break. An alarm system should be tied into the arm drive motor mechanism, in case it does have a malfunction and stops. The operator should check the sludge pumping rates each day to make sure that the right amount of sludge is still being pumped. This check should be based on some type of flowmeter and not on pump motor readings, because the motor may be running but the pump may not be pumping.

Methane could develop very easily because of the presence of such a large quantity of sludge at zero dissolved oxygen. The monitor is also very important because the sludge condition may be proper, but an industrial discharge could unexpectedly put some type of combustible material in the system. Please refer to Sewer Collection Evaluation, Section I,D for alarm settings.

As discussed in the Primary Sedimentation Rectangular Enclosed and Rectangular Open Tank sections, most of the problems come from the sludge. Listed below are various conditions that will cause rising or septic sludge:

1. Broken sludge collection arm (no rotation)

2. Sludge pumping rate too low

3. Surface loading too high

4. Detention time too long (in excess of 3 hours)

Sulfide gas could also cause a serious problem to anyone working in these areas by its toxicity. If this condition does occur, all personnel should be notified. With both sulfide and combustible monitors in the tank, the operator will know about this problem before it gets critical, so that some of the sludge can be pumped out of the tank as soon as possible. Even when the tank is empty for repairs, the two atmosphere monitors should stay activated. If the covers are removable, they should be removed completely before repair personnel enter the area. It should be remembered that the big factors are the sludge blanket and sludge. If an operator sees any signs of rising sludge, action should be taken immediately before hazards develop. The tanks should never be allowed to get into a condition where methane gas is being produced from septic conditions.

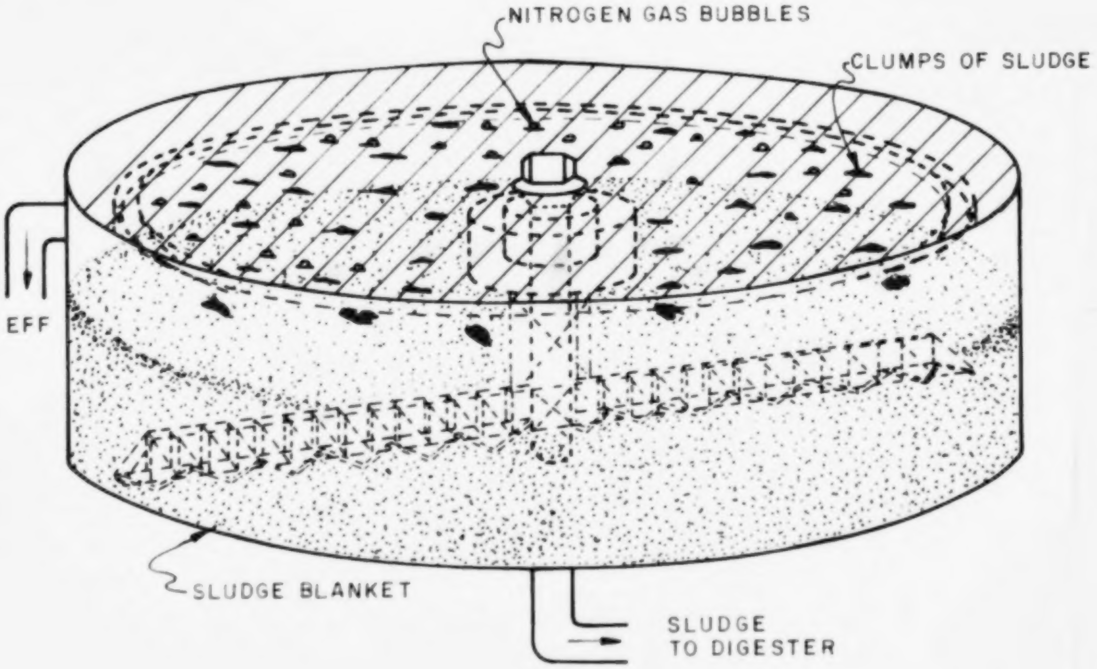

NITROGEN GAS BUBBLES
CLUMPS OF SLUDGE
EFF
SLUDGE BLANKET
SLUDGE
TO DIGESTER

Figure 22. Enclosed Circular Primary Sedimentation Tank-Inadequate Operation

2. Vented Configurations

The following applies only to systems using recirculation blowers for mixing. If the blower is pulling the vapors off the top of the sedimentation tank and pushing them into the aeration tanks, any problems would be moved from one tank to another. If for some reason the blower is overheated because of running it near or in a surge condition, any methane could explode inside the blower. Therefore, the blower should always operate in the proper range as called for by the discharge gauge. Of course, with an oxygen enriched environment in the enclosed aeration tank, the problem is magnified because if there are any leaks in the cover, an operator could easily ignite the methane. Even with an open aeration tank these vapors are pushed up through the liquid into the atmosphere where they could be ignited, since methane gas is practically insoluble in water. If the tank is vented to the atmosphere, gases could be released all around the sedimentation tank where they could be toxic or explosive.

3. Liquid Monitoring

Analysis for hydrocarbons is needed to detect petroleum products such as solvents and oils that may have gotten past the headworks.

4. Atmospheric Monitoring

Sulfides or methane could be forced into the tank from the headwork area by improper conditions. These gases could enter with the sewage or be produced in the wet well. If these levels are satisfactory in the headworks area but not in the sedimentation tank, the operator should realize immediately that the sedimentation tank is not being operated properly. An enclosed tank should have a sulfide monitor in it to warn the operator of toxic conditions before entering the area, to avoid being overcome by toxic gases. Sulfides should be below the toxicity level of 0.001 percent in air by volume. Your nose cannot be relied upon for sulfide detection because small concentrations 100 ppm can paralyze the olfactory nerve and prevent sulfide detection. Methane monitoring is also a must in an enclosed tank because methane is odorless and explosive. In this way the operator would be made aware of explosive conditions before entering the area. Methane should be below the explosive level of 5 percent in air by volume. Oxygen monitoring is also a must, especially if a worker has to enter a tank for repair work. An oxygen mask should be used if the oxygen content is less than 20 percent.

5. Total Alarm System

The following are conditions and results which a total alarm system can detect and aid to control.

1. Methane--Explosive in that area and can possibly be pushed into other areas where it could be explosive.

2. Sulfides--Toxic in that area and can possibly be pushed into other areas where they could be toxic or explosive.

3. Oxygen--May fall below an acceptible concentration in air, when an operator must be alerted to wear an oxygen mask before entering the tank.

4. Sludge Collection Equipment--Any malfunction must be detected to let an operator know immediately if the removal of sludge has been affected, so that the problem can be corrected before anaerobic conditions develop.

6. Treatment Equipment

The treatment equipment consists of the following:

1. Sludge Collection Equipment

2. Sludge Pumps (for sludge removal)

3. Explosive proof motors and anti-sparking tools

G. SAFETY CHECKLIST FOR PRIMARY SEDIMENTATION

The following are items to be checked and complied with:

1. Check that sludge pumping rates are adequate and have not decreased, because then the sludge blanket will rise to the top and come out of the tank with the effluent. Also, the sludge will turn anaerobic and form sulfides and methane. Check that the sludge pump is not plugged, that no valves have been closed, and that the drive belts are not slipping.

2. Check sludge collection equipment such as chains, flights, rotating arms and drive motors. If this equipment stops functioning, sludge will not be removed properly and it will turn anaerobic and form methane and sulfides. If everything is operating correctly and the sludge blanket is higher than normal, the solids flowrate into the plant is higher than usual. This could be the result of sewer cleaning or an industrial waste discharge. If the sludge blanket is too high, increase the sludge pumping rate enough to bring the blanket down to a normal operating level which is approximately 1/3 up the vertical height of the tank.

3. Skim grease off the effluent surface and wash down all exposed or residual grease and solids above the water level. This will help prevent the formation of anaerobic conditions. Pump all grease to the digester or disposal area and flush the pump and line.

4. Check all ventilation openings to ensure that they are not stuck closed. If they get corroded closed, a positive pressure could develop under a cover, and combustible and toxic gases could concentrate.

5. Make sure that the drive motors are not overheated, because they could ignite any combustible gas mixture around the tank.

6. Check to see that all monitors are operating correctly. These monitors indicate to the operator any dangerous conditions that may result from inflow into the tank or exist in the outflow from the tank. This will also indicate any problems that may exist in the aeration tank.

7. Flush out all sludge lines and leave one end open to the atmosphere. In this way if anaerobic conditions develop, the small amounts of methane and sulfides formed will be vented out of the open end of the lines.

H. OXYGEN AERATION ACTIVATED SLUDGE REACTOR - ENCLOSED

Enclosed oxygen aeration activated sludge reactors may be single-stage or multi-stage, with initial oxygen entry into the freeboard or through submerged spargers. For best oxygen utilization freeboard gas (consisting principally of oxygen and carbon dioxide in various proportions, depending on the particular stage) may be recirculated by compressors to submerged re-injection points, and mixing devices may be employed on or below the liquid surface. Various combinations of these features are possible, resulting in reactors of great variety. However, three main types of enclosed reactors have found use in practice, and these will be illustrated:

1. Multi-stage; initial oxygen entry into freeboard of Stage 1 with subsequent deep submerged injection through spargers by recirculation compressors; submerged turbine type rotary mixers (Figure 23):

   Detroit - Figures 24 and 25 (from Ref. 1)
   Newtown Creek, Brooklyn - Figure 26 (from Ref. 2)
   EPA-DC Pilot Plant, Blue Plains - Figure 27 (from Ref. 2)

2. Multi-stage; initial oxygen entry into freeboard of Stage 1 with dissolution by surface aeration rotary mixer; co-axial submerged turbine type rotary mixer (Fig. 28):

   Speedway, Indiana - All stages covered
   Westgate Plant, Fairfax County, Virginia - Last stage open - Figure 29 (from Ref. 3)

3. Single-stage; oxygen enters through submerged spargers; gas in freeboard recirculated to conventional (air) diffusers; Tapia plant, Las Virgenes MWD, Calabasas, California - Figure 30

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TOP OF IMAGE AREA
DROPPED HEAD, BEGIN SECTIONS HERE

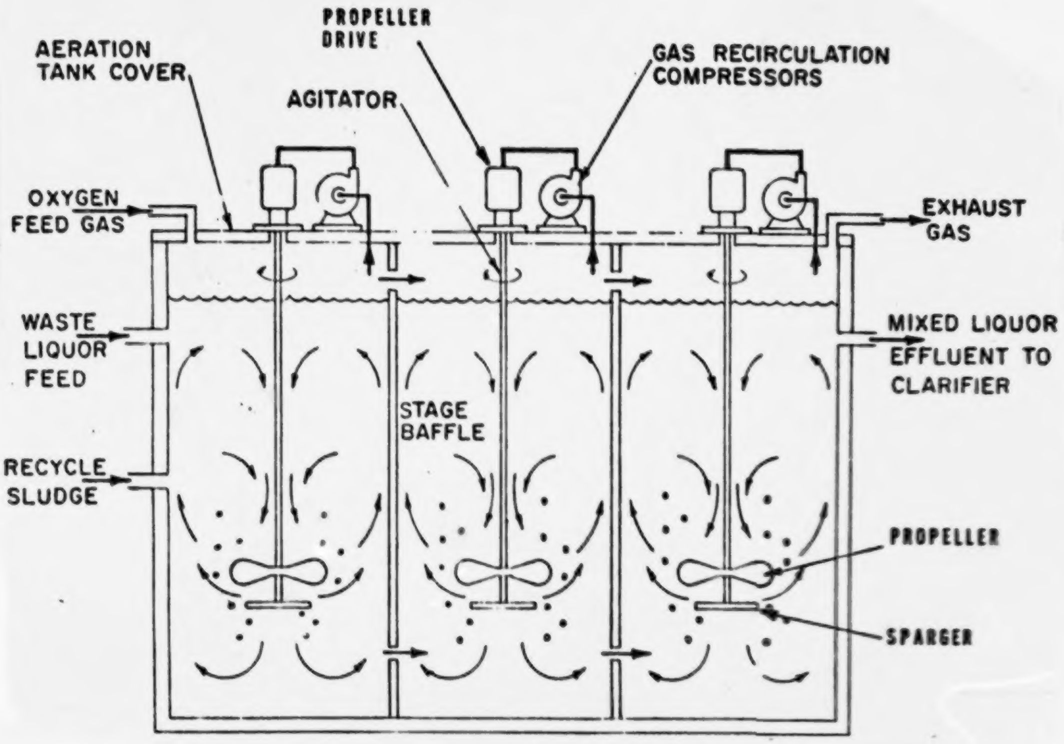
PROPELLER DRIVE
AERATION TANK COVER
GAS RECIRCULATION COMPRESSORS
AGITATOR
OXYGEN FEED GAS
EXHAUST GAS
WASTE LIQUOR FEED
MIXED LIQUOR EFFLUENT TO CLARIFIER
STAGE BAFFLE
RECYCLE SLUDGE
PROPELLER
SPARGER

Figure 23. Schematic Diagram of Multistage, Covered-Tank Oxygenation System With Gas Recirculation Compressors and Submerged Turbine/Spargers (from Ref. 2)

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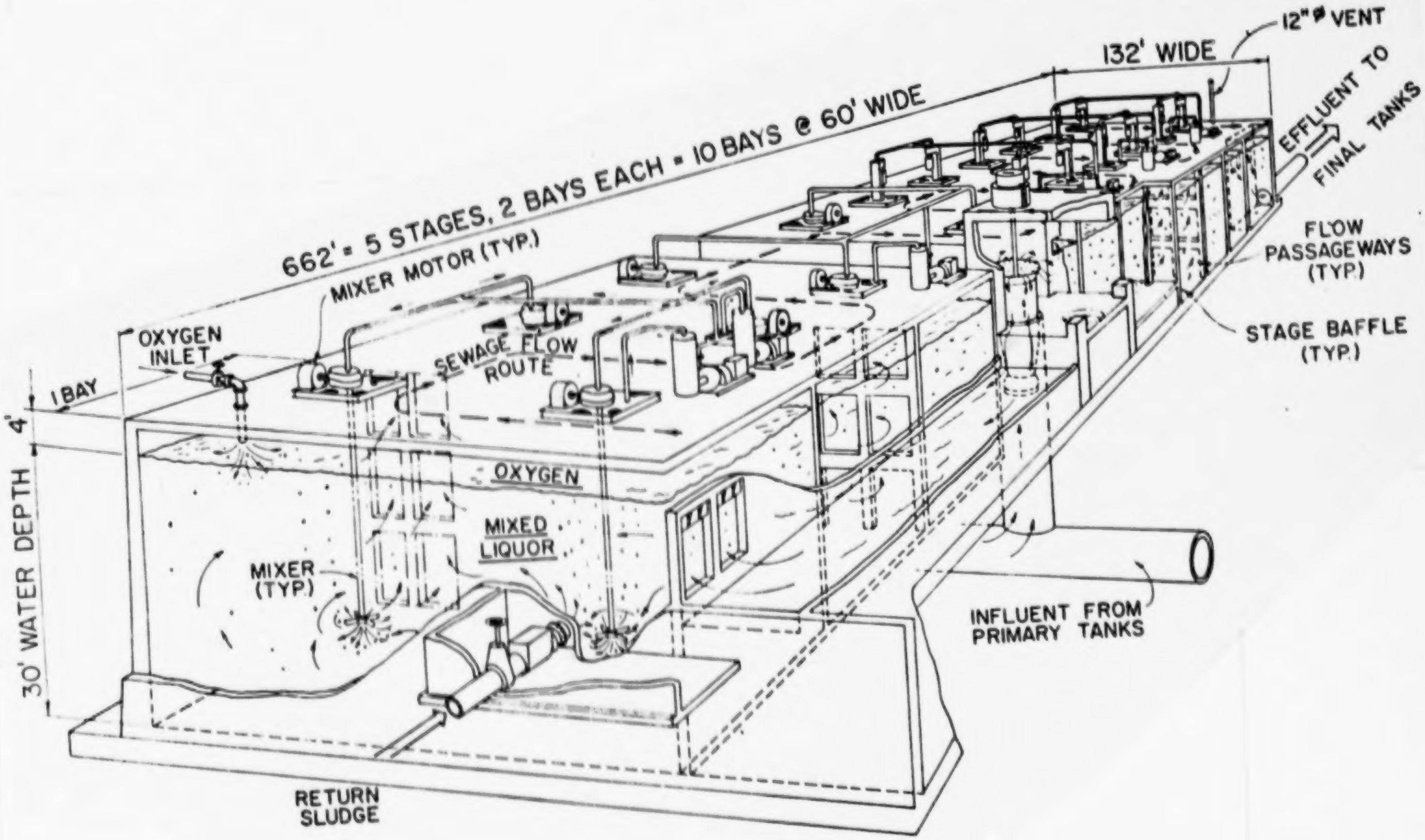
12"ø VENT
132' WIDE
662' = 5 STAGES, 2 BAYS EACH = 10 BAYS @ 60' WIDE
EFFLUENT TO FINAL TANKS
FLOW PASSAGEWAYS (TYP.)
STAGE BAFFLE (TYP.)
MIXER MOTOR (TYP.)
OXYGEN INLET
SEWAGE FLOW ROUTE
1 BAY
4'
OXYGEN
MIXED LIQUOR
MIXER (TYP.)
30' WATER DEPTH
INFLUENT FROM PRIMARY TANKS
RETURN SLUDGE

Figure 24. Oxygen Aeration System, Detroit (from Ref. 1)

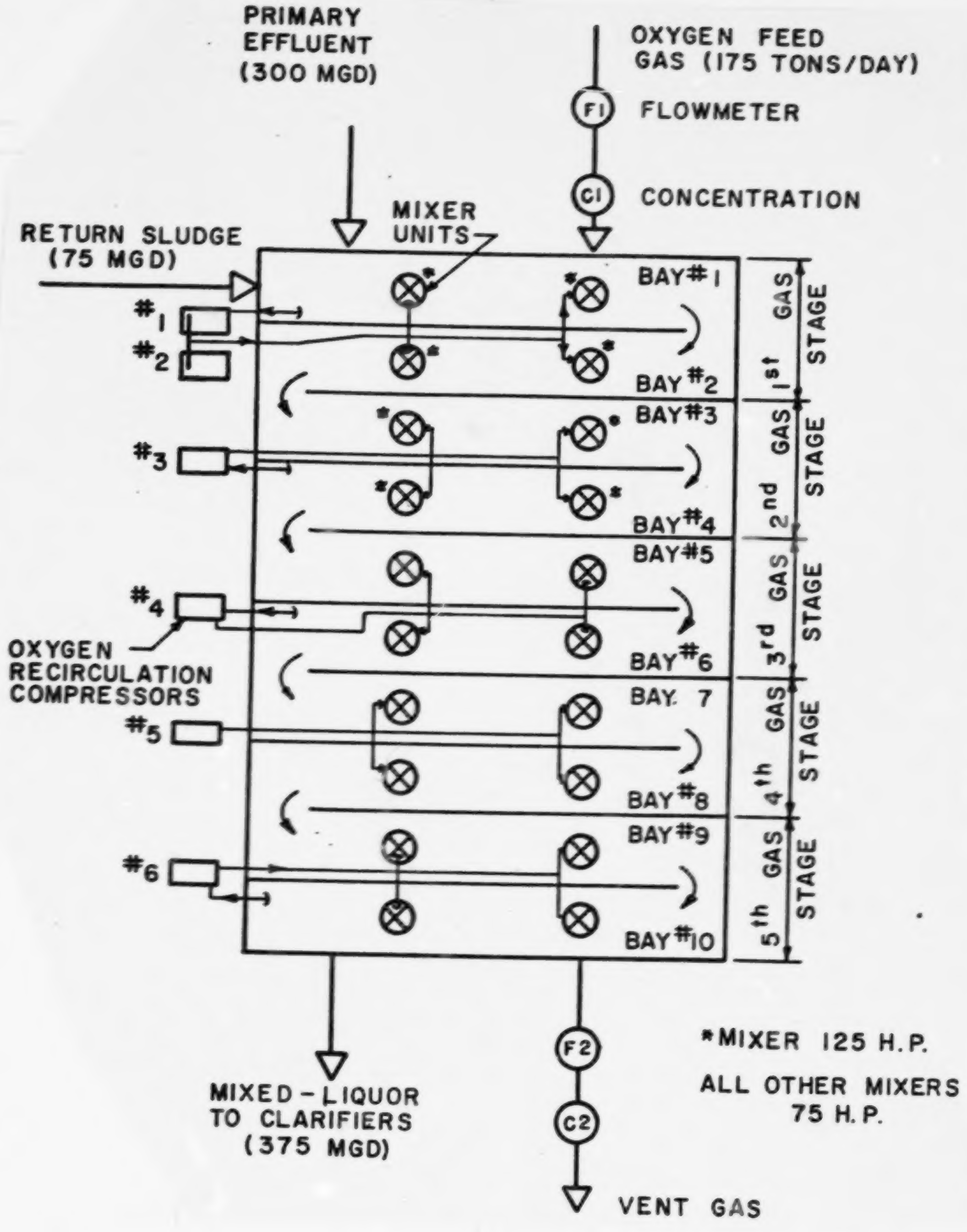
PRIMARY EFFLUENT (300 MGD)
OXYGEN FEED GAS (175 TONS/DAY)
FI
FLOWMETER
CI
CONCENTRATION
MIXER UNITS
RETURN SLUDGE (75 MGD)
#1
#2
#3
#4
#5
#6
OXYGEN RECIRCULATION COMPRESSORS
BAY #1
BAY #2
BAY #3
BAY #4
BAY #5
BAY #6
BAY 7
BAY #8
BAY #9
BAY #10
1st GAS STAGE
2nd GAS STAGE
3rd GAS STAGE
4th GAS STAGE
5th GAS STAGE
F2
C2
*MIXER 125 H.P.
ALL OTHER MIXERS 75 H.P.
MIXED-LIQUOR TO CLARIFIERS (375 MGD)
VENT GAS

Figure 25. Oxygen Treatment Schematic, Detroit (From Ref. 1)

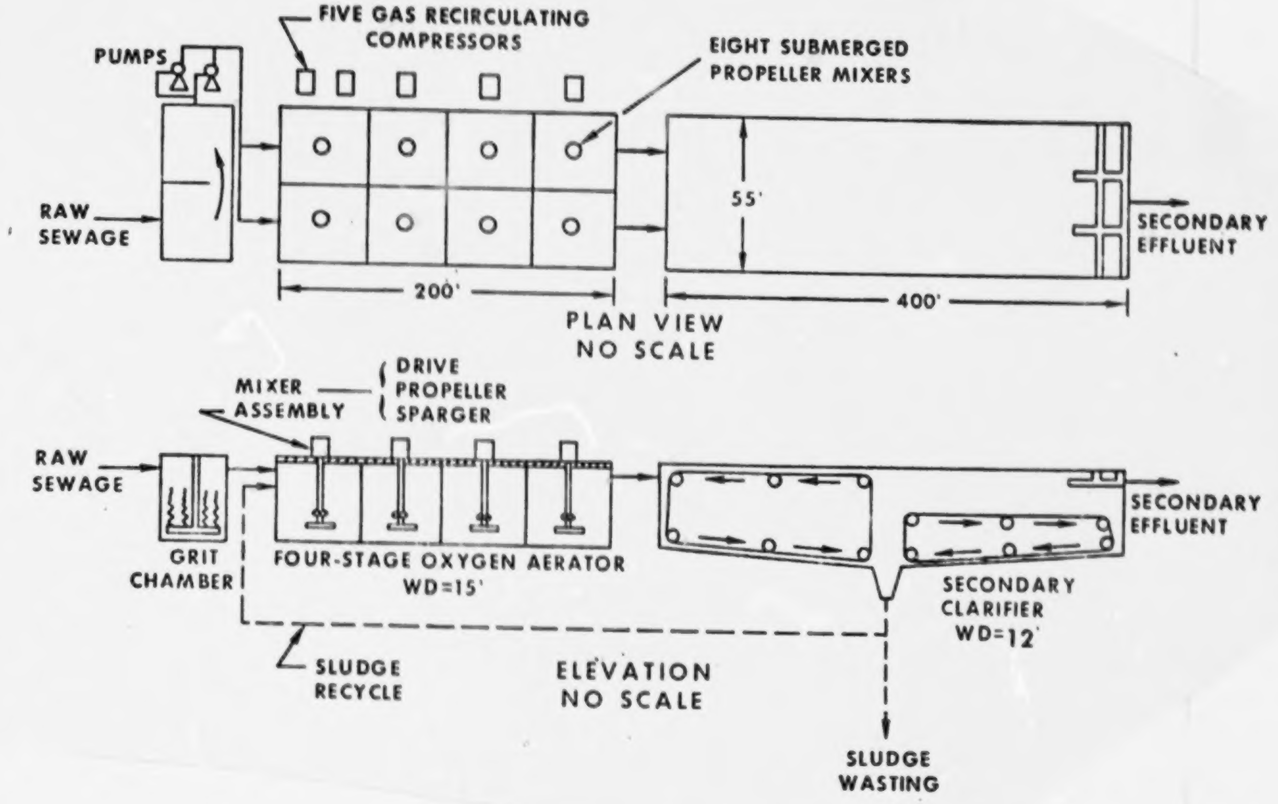
FIVE GAS RECIRCULATING COMPRESSORS
PUMPS
EIGHT SUBMERGED PROPELLER MIXERS
RAW SEWAGE
55'
SECONDARY EFFLUENT
200'
400'
PLAN VIEW NO SCALE
MIXER ASSEMBLY
DRIVE
PROPELLER
SPARGER
RAW SEWAGE
GRIT CHAMBER
FOUR-STAGE OXYGEN AERATOR WD=15'
SECONDARY EFFLUENT
SECONDARY CLARIFIER WD=12'
SLUDGE RECYCLE
ELEVATION NO SCALE
SLUDGE WASTING

Figure 26. Plan and Elevation Views of Oxygen Aeration Test Bay, Newton Creek, Brooklyn, New York (From Ref. 2)

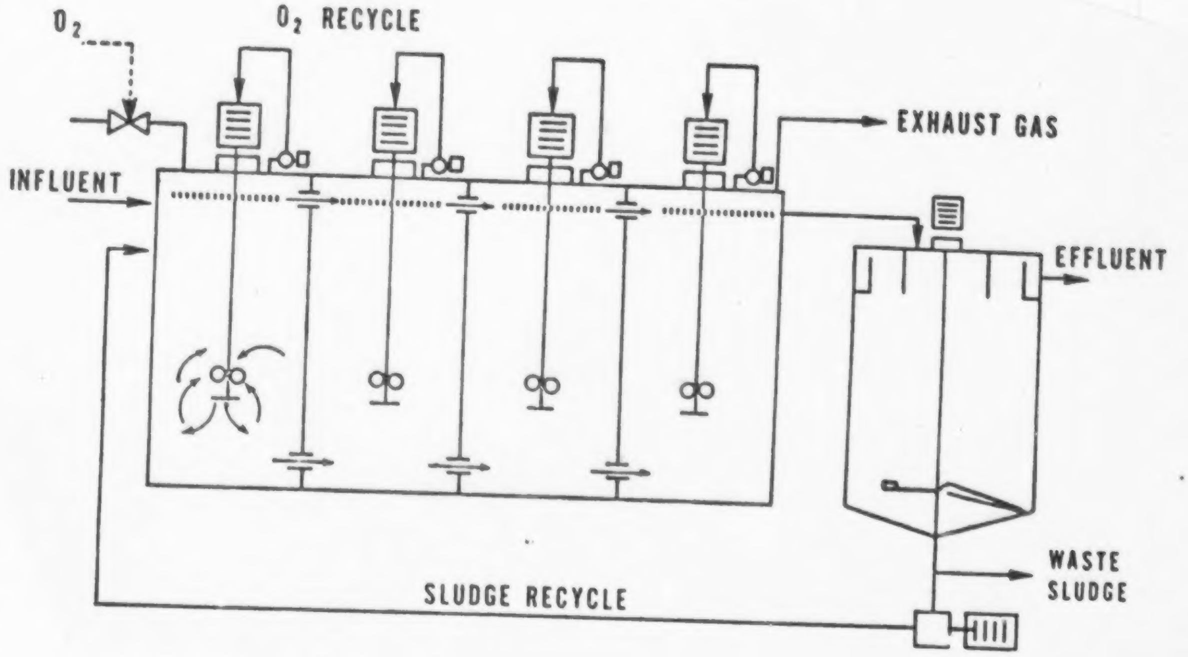
O_2
O_2 RECYCLE
EXHAUST GAS
INFLUENT
EFFLUENT
WASTE SLUDGE
SLUDGE RECYCLE

Figure 27. Schematic Diagram of Blue Plains Oxygenation System (EPA-DC Pilot Plan) (Ref. 2)

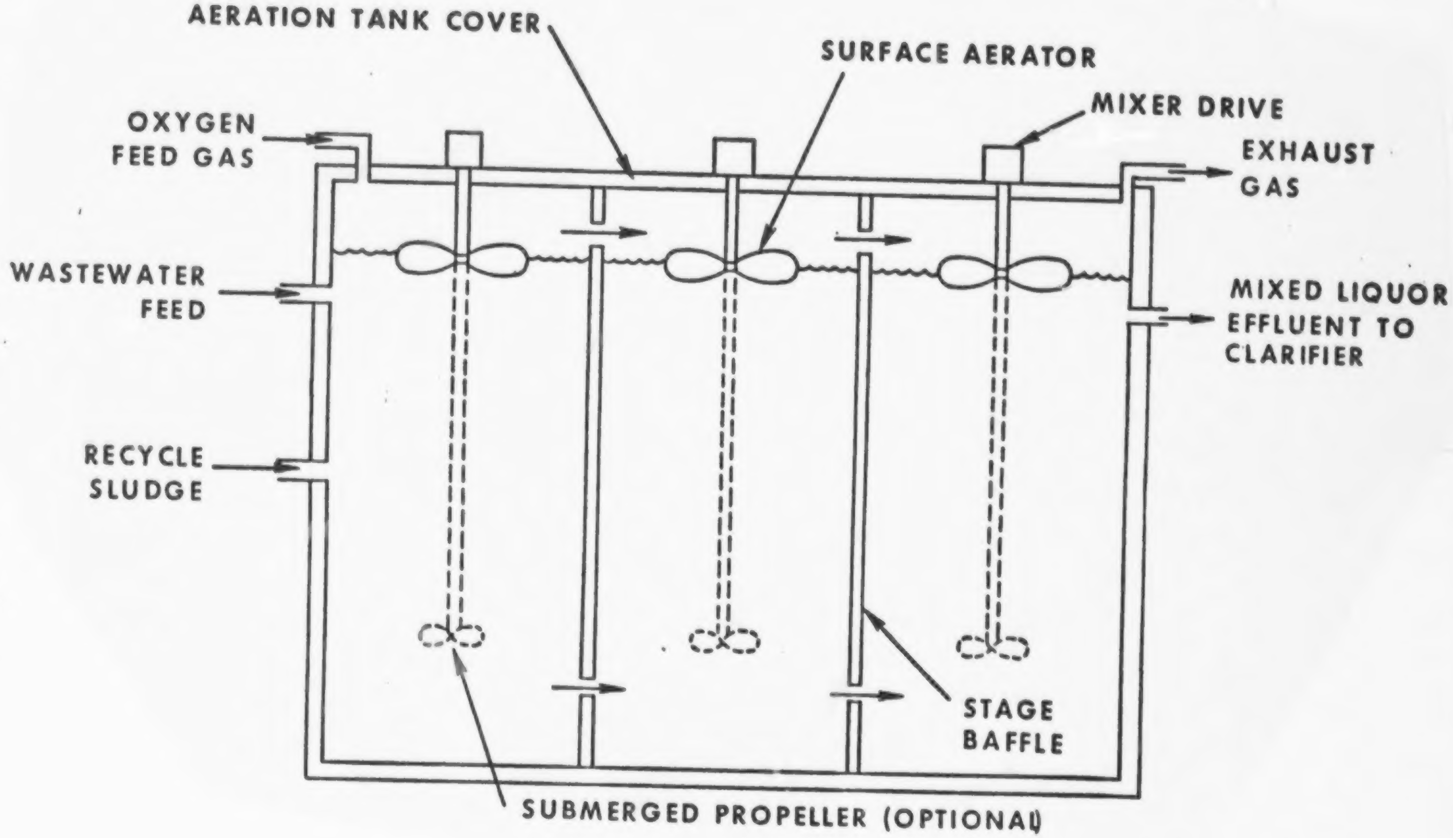
AERATION TANK COVER
SURFACE AERATOR
MIXER DRIVE
OXYGEN FEED GAS
EXHAUST GAS
WASTEWATER FEED
MIXED LIQUOR EFFLUENT TO CLARIFIER
RECYCLE SLUDGE
STAGE BAFFLE
SUBMERGED PROPELLER (OPTIONAL)

Figure 28. Schematic Diagram of Multistage, Covered-Tank Oxygenation System With Surface Aerators (Ref. 2)

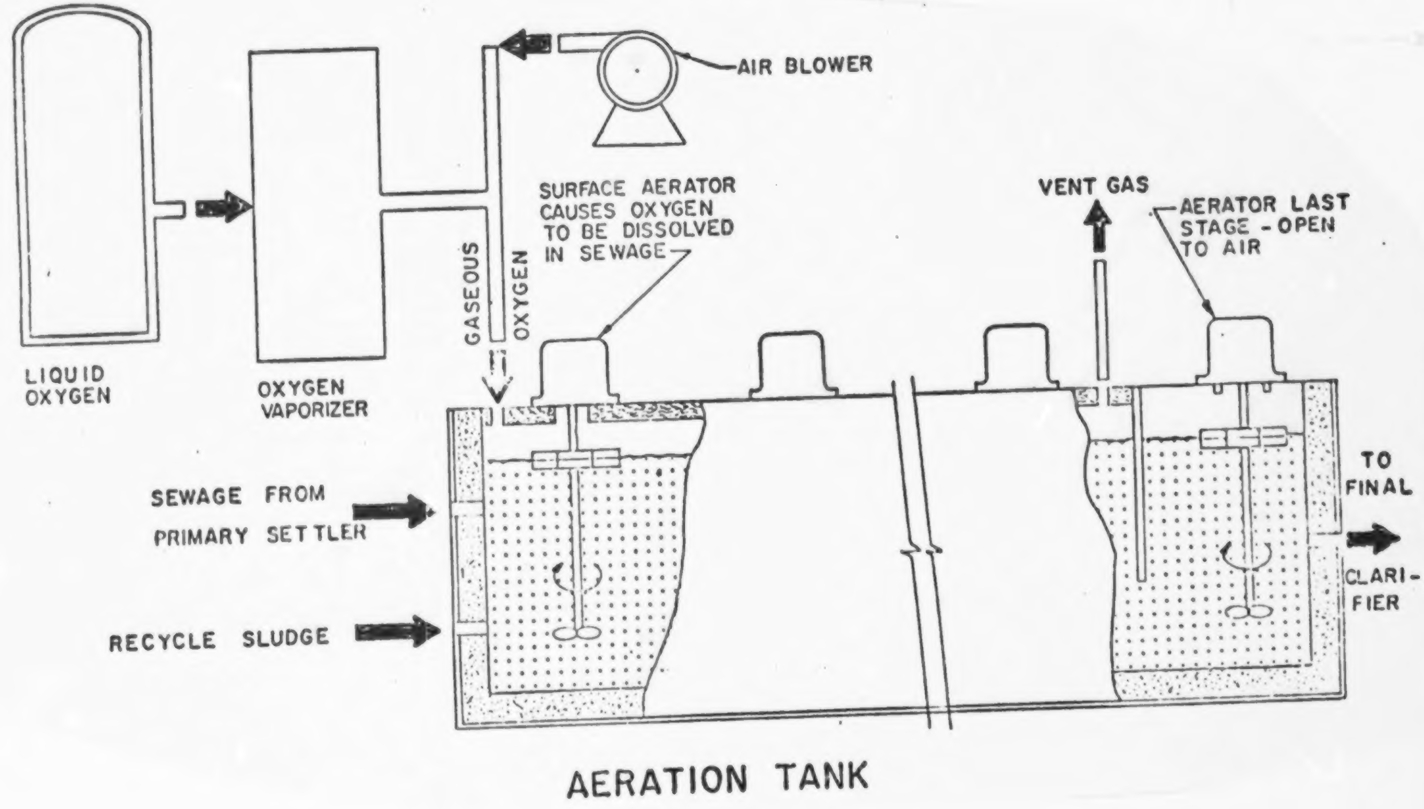
AIR BLOWER
SURFACE AERATOR CAUSES OXYGEN TO BE DISSOLVED IN SEWAGE
VENT GAS
AERATOR LAST STAGE - OPEN TO AIR
GASEOUS OXYGEN
LIQUID OXYGEN
OXYGEN VAPORIZER
SEWAGE FROM PRIMARY SETTLER
RECYCLE SLUDGE
TO FINAL CLARIFIER
AERATION TANK

Figure 29. Westgate Oxygen Activated Sludge System, Fairfax County, Virginiz (From Ref. 3)

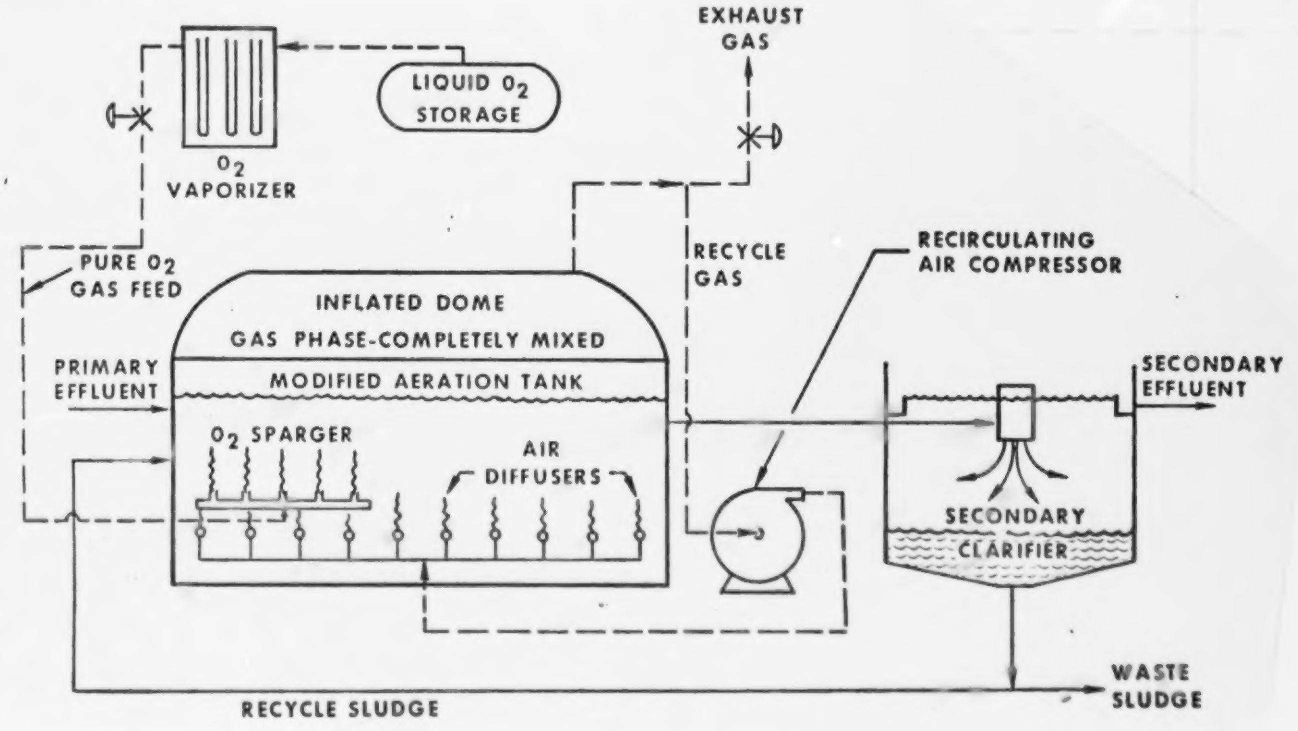
EXHAUST GAS
LIQUID O_2 STORAGE
O_2 VAPORIZER
PURE O_2 GAS FEED
RECYCLE GAS
RECIRCULATING AIR COMPRESSOR
INFLATED DOME
GAS PHASE-COMPLETELY MIXED
MODIFIED AERATION TANK
PRIMARY EFFLUENT
O_2 SPARGER
AIR DIFFUSERS
SECONDARY EFFLUENT
SECONDARY CLARIFIER
WASTE SLUDGE
RECYCLE SLUDGE

Figure 30. Schematic Diagram of Diffused Air Aeration System Modified to Recirculate Oxygen Gas, Las Virgenes Project, Tapia Plant, Calabasas, California (From Ref. 2)

The illustrations show that enclosed multi-stage reactors include electric motors to drive mixers and compressors in many locations in the various stages. This rotating machinery brings with it potential mechanical and electrical hazards. The possibility of structural failure of the top deck of an enclosed reactor tank due to over-or under-pressure in the freeboard must be counteracted by relief valves set for both pressure and vacuum.

The process control is either through disolved oxygen demand in the mixed liquor or to maintain a given gas pressure in the freeboard. In the latter case a vent at the downstream end of the reactor maintains the pressure profile along the flow direction. With oxygen concentration in the vent gas at 1/2 to 1/3 of the initial high-purity value at entry, over 90 percent oxygen utilization is achieved.

1. Potential Hazards

Typical single-stage oxygen aeration activated sludge reactors, with recirculation auxiliary equipment and safety monitors are shown in Figures 31 and 32. The safety-oriented discussion which follows, applies also to multistage reactors. Sulfides and methane could enter from the sewer line, headworks, or sedimentation tank if any of these are improperly operated, as discussed earlier. These gases could also be produced in the activated sludge reactor if this is not operated properly. If there is not enough oxygen supplied for aeration and the dissolved oxygen in the mixed liquor goes to zero, sulfides and methanes will be produced. Listed below are some conditions that could cause this to happen:

1. Loss of feed oxygen
2. Overload of oxygen-consuming materials
3. Incorrect readings on dissolved oxygen probes
4. Failure of oxygen recirculation blowers or mixers

Sulfide and methane could form very easily under these conditions with no dissolved oxygen. If there were a leak in the cover, these gases would be carried out, and personnel in the area could be overcome by the toxic sulfide or the flammable methane could be ignited. These gases could also be pulled into an overheated blower and explode. The atmosphere in an enclosed reactor is never safe under any conditions for anyone to enter without wearing a self-contained oxygen mask. Shoes and tools inside the reactor should be made of antisparking material. If for some reason the oxygen feed is shut off, the dissolved oxygen content in the aeration tank will drop to zero very quickly and methane and sulfides will form.

If an unexpected load of organic material comes into the plant it will put an immediate oxygen demand on the aeration reactor. This material could come from sewer cleaning work, or from primary sedimentation if bulking occurs and solids become part of the primary effluent.

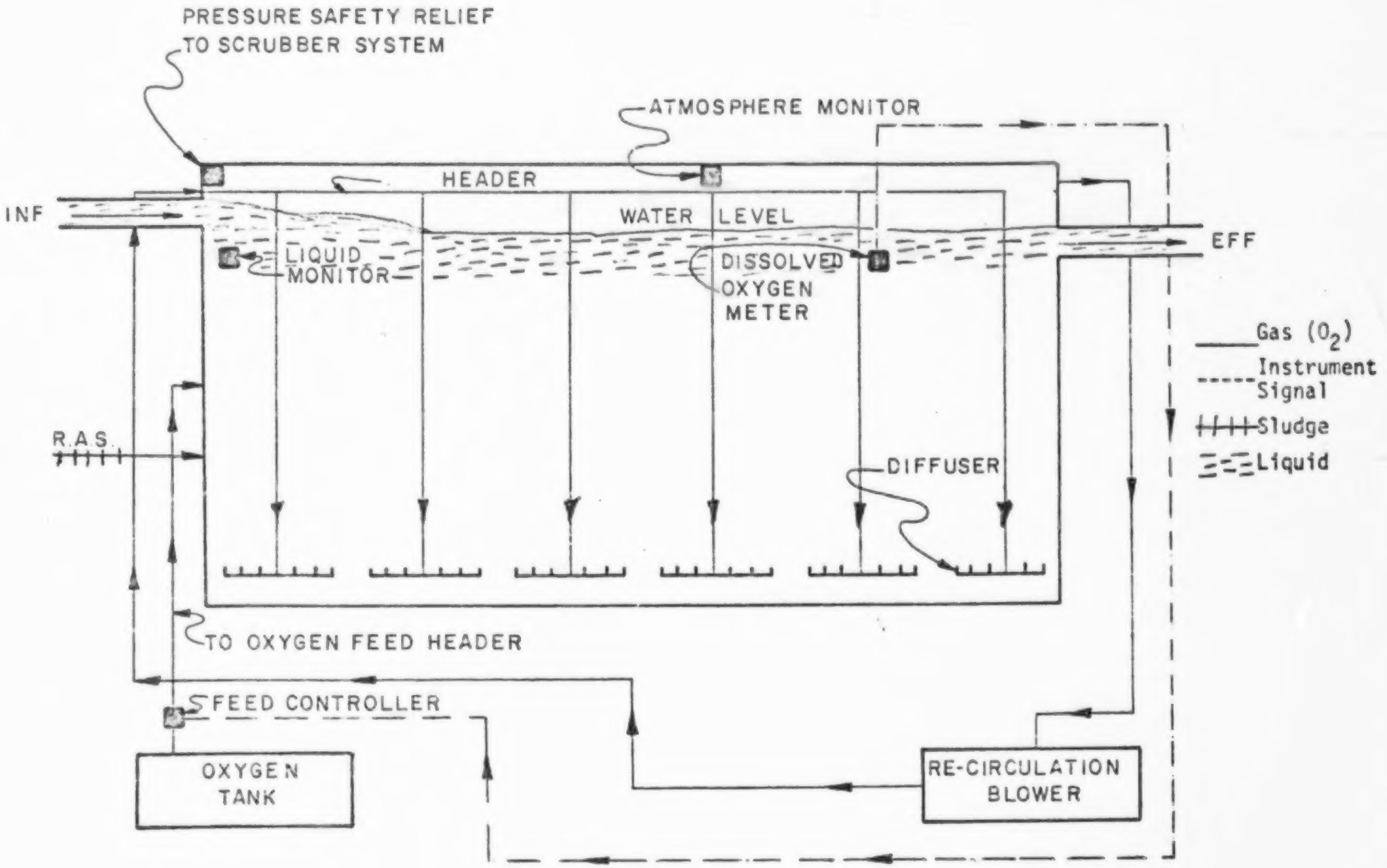
PRESSURE SAFETY RELIEF
TO SCRUBBER SYSTEM
ATMOSPHERE MONITOR
HEADER
INF
WATER LEVEL
EFF
LIQUID
MONITOR
DISSOLVED
OXYGEN
METER
Gas (O_2)
Instrument Signal
Sludge
Liquid
R.A.S.
DIFFUSER
TO OXYGEN FEED HEADER
FEED CONTROLLER
OXYGEN
TANK
RE-CIRCULATION
BLOWER

Figure 31. Adequate Enclosed Oxygen Aeration Reactor Tank (Single-Stage Reactor With Recirculation Shown)

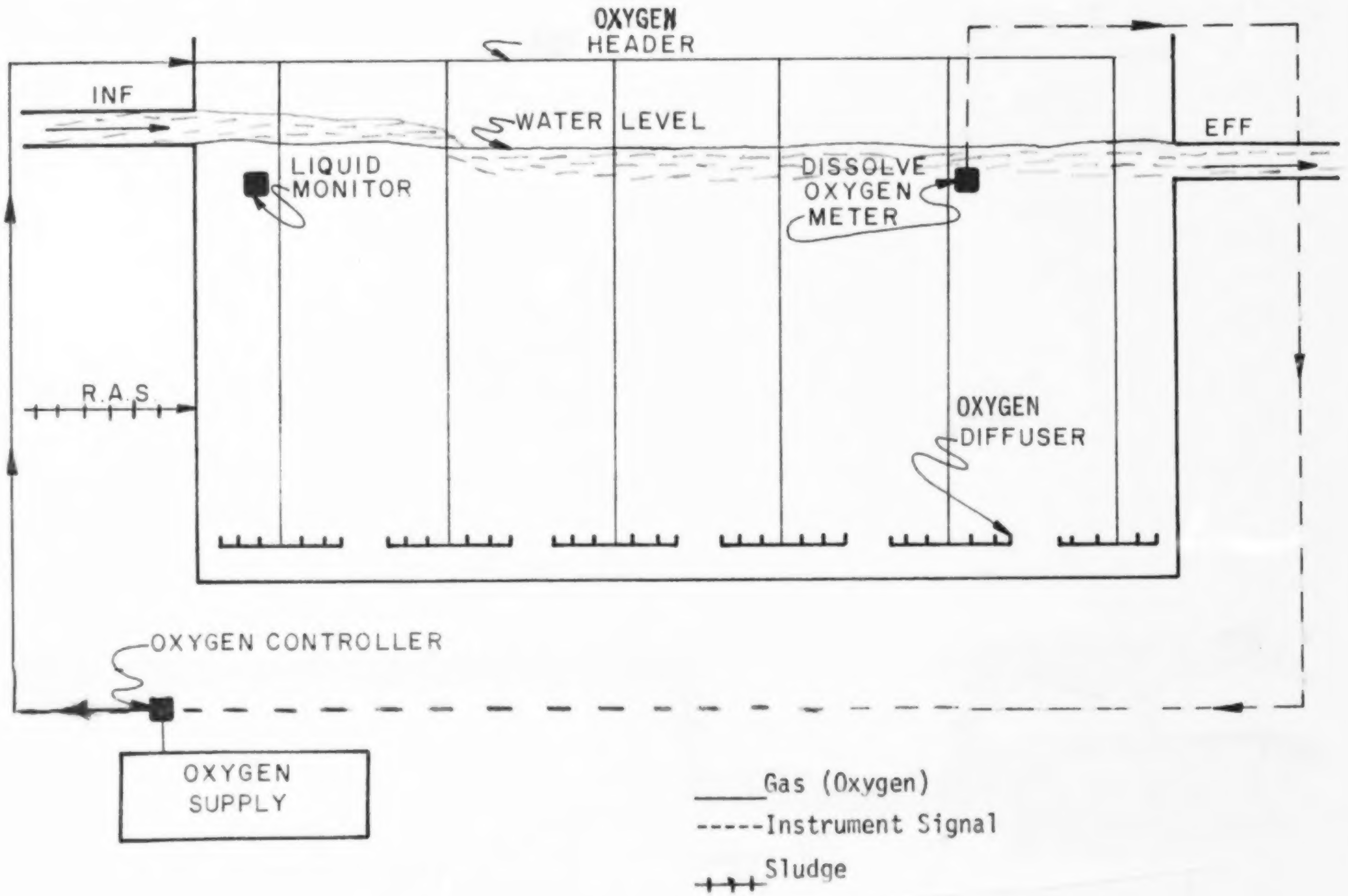
OXYGEN
HEADER
INF
WATER LEVEL
EFF
LIQUID
MONITOR
DISSOLVE
OXYGEN
METER
R.A.S.
OXYGEN
DIFFUSER
OXYGEN CONTROLLER
OXYGEN
SUPPLY
Gas (Oxygen)
-----Instrument Signal
Sludge

Figure 32. Adequate Open Oxygen Aeration Reactor Tank (Single-Stage Reactor Shown)

The dissolved oxygen probes should be used for operating the aerator as long as it is certain that they are reading correctly. If the oxygen feed is regulated by the dissolved oxygen probe reading and the reading is high it will not call for more oxygen and as a result the dissolved oxygen in the system could go to zero. The atmosphere under the cover is about 30 percent carbon dioxide under normal operating conditions. The atmosphere is not suitable for normal breating. The carbon dioxide concentration, of course, will increase with the depletion of oxygen in the reactor which might be caused by some of the preceding problems.

All hazards discussed here could occur in the secondary sedimentation system. Besides all the normal problems, combustible solvents and heavy loads of suspended solids could come in from various types of industry as shown in Table 2. With industry on the sewer system, everything in the plant can be well maintained, but conditions could change in a few hours. An influent of combustibles could create explosive conditions anywhere in the sewer system and treatment plant. Methane and sulfides could be produced more easily with high oxygen demand material going into the aeration reactor.

2. Vented Configuration

Vented configurations have relief valves to avoid overpressure or vacuum acting on the top cover. A tank that is vented to the atmosphere could be an immediate problem to the surrounding area by releasing toxic combustibles and sulfides. Of course, these would only be formed in the tank if it were not being operated properly, as discussed above. If the tank were being properly operated, there would be no hazardous gases vented, unless industry were to dump material into the system without warning.

If this condition should remain for several hours, there would be a massive generation of sulfides and methane gas in the atmosphere under the cover, and an ignition source would cause a catastrophic explosion. An operator should have plenty of warning before a tank ever gets into this condition. First of all, with pure oxygen, if the feed is decreasing or interrupted, there should be a standby oxygen and/or air system to put on line immediately.

An atmosphere monitor should analyze for sulfides, combustibles, and oxygen content. As discussed before, the alarm should sound when sulfides exceed 0.001 percent, combustibles exceed 5 percent, or oxygen falls below 19.5 percent. With these indications, normal problems should be averted before they arise. In the liquid, there should be dissolved oxygen probes with monitors and alarms. The oxygen feed regulation should be based on the dissolved oxygen probe readouts, in addition to merely maintaining a positive oxygen head over the mixed liquor. The dissolved oxygen should be kept at a minimum of 0.5 mg/l. If the tank receives a shock load of oxygen-demanding material and the dissolved oxygen starts to decrease, the probe should signal the oxygen controller for more oxygen feed.

Personnel exposed to oxygen leaks should stay away from any open flames and not smoke for at least 1 hour to give their clothing a chance to dissipate some of the oxygen that collected in them.

The reactor should be equipped with a safety pressure relief valve. In case the valve on the suction side of a recirculation blower fails and the oxygen feed continues, a high pressure might develop. If it does, the excess pressure should be released through a scrubber system and not to the atmosphere because of the potential problem gases that may be vented.

The aeration reactor should never be entered if at all avoidable. If an operator has to enter, a self-contained air mask and nonsparking attire must be worn, and nonsparking equipment must be used. A combustible solvent discharged into the sewer could enter the closed oxygen-enriched atmosphere where it could be an unforeseen problem. It could form an explosive condition under the cover and in the recirculation blower if one is used.

3. Atmosphere Monitoring

Monitors and alarms should be installed for the following potentially hazardous gases:

Sulfides	Toxic above 0.001 percent by volume
Methane	Explosive above 5 percent by volume
Hydrocarbon	Explosive, keep below 25 percent of lower explosion limit

All of these monitors would be necessary because all of these gases could be brought into the reactor from the sewer line or sedimentation tank. The monitors permit the operator to immediately know if any hazardous gas is present. Introducing combustibles into an oxygen-enriched atmosphere will form explosive conditions at once. If the reactor is not properly operated the dissolved oxygen in the liquid goes to zero. Of course, any heavy concentrations of industrial waste would magnify the problem.

4. Liquid Monitoring

A dissolved oxygen probe will be necessary for the operator to know if the dissolved oxygen approaches zero. If this happens sulfides and methane will be generated. The possible problems are spelled out in Section II,H,1,Potential Hazards. Combustible solvents also should be monitored so that explosive conditions could be detected or anticipated.

5. Total Alarm System

The following should be monitored and an alarm should indicate hazardous conditions:

Material	Hazard	Condition
Sulfides	Toxic	0.001 percent maximum (8 hours)
Methane	Explosive	5 percent maximum
Oxygen	Asphyxiation	Indication
Carbon Dioxide	Asphyxiation	Indication
Dissolved Oxygen		0.5 mg/l minimum

These alarms warn the operator of problem conditions which enter the tank, arise in the tank, or leave the tank. If the operator maintains a minimum dissolved oxygen 0.5 mg/l in the reactor, the sulfides and methane will not be produced, but other combustibles could enter the tank (e.g., from industrial discharge) and form explosive conditions. While carbon dioxide and oxygen concentration limits in the atmosphere are not specified above, they should be known for use in reactor operation and entrance safety. No one should enter an enclosed reactor without self contained breathing oxygen under any circumstances.

6. Treatment Equipment

Treatment equipment consists of the following: blower for oxygen supply and mixing; air and oxygen headers and diffusers for supply and mixing; oxygen feed supply; and dissolved oxygen probes, used to maintain aerobic condition.

I OXYGEN AERATION ACTIVATED SLUDGE REACTOR - OPEN

Open oxygen aeration activated sludge reactors utilize subsurface oxygen injection together with some means of mixing, which may be mechanical or fluid-fluid in nature. Two systems have been reduced to practice:

1. Direct oxygen injection at high pressure (to 30 psig) through submerged fine bubble fixed active diffusers:

   Denver - 1/2 mgd pilot plant

   Englewood, Colorado - 0.05 mgd pilot plant - Figure 33 (from Ref. 2)

2. Immersed concrete module; oxygen enters module gas space; mixed liquor pumped through module:

   Wayne, New Jersey - Figure 34 (from Ref. 4)

Both these systems employ mixed liquor recirculation as a mixing device with the oxygen. Because of the absence of confined spaces this type of reactor is relatively safe compared to the enclosed type. If any sulfides or hydrocarbons come into the tank they will be flushed out immediately with the

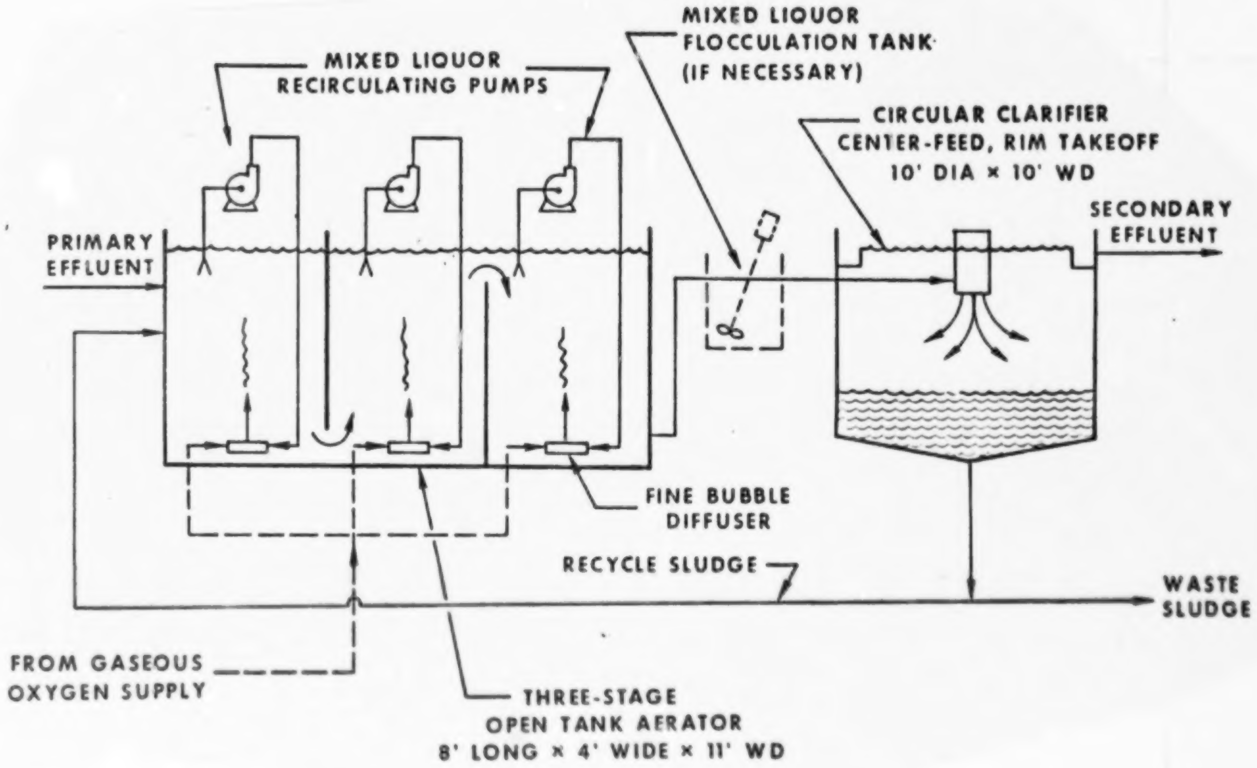
MIXED LIQUOR
RECIRCULATING PUMPS
MIXED LIQUOR
FLOCCULATION TANK
(IF NECESSARY)
CIRCULAR CLARIFIER
CENTER-FEED, RIM TAKEOFF
10' DIA × 10' WD
SECONDARY
EFFLUENT
PRIMARY
EFFLUENT
FINE BUBBLE
DIFFUSER
RECYCLE SLUDGE
WASTE
SLUDGE
FROM GASEOUS
OXYGEN SUPPLY
THREE-STAGE
OPEN TANK AERATOR
8' LONG × 4' WIDE × 11' WD

Figure 33. Open-Tank Oxygenation Pilot System, Englewood, Colorado (From Ref. 2)

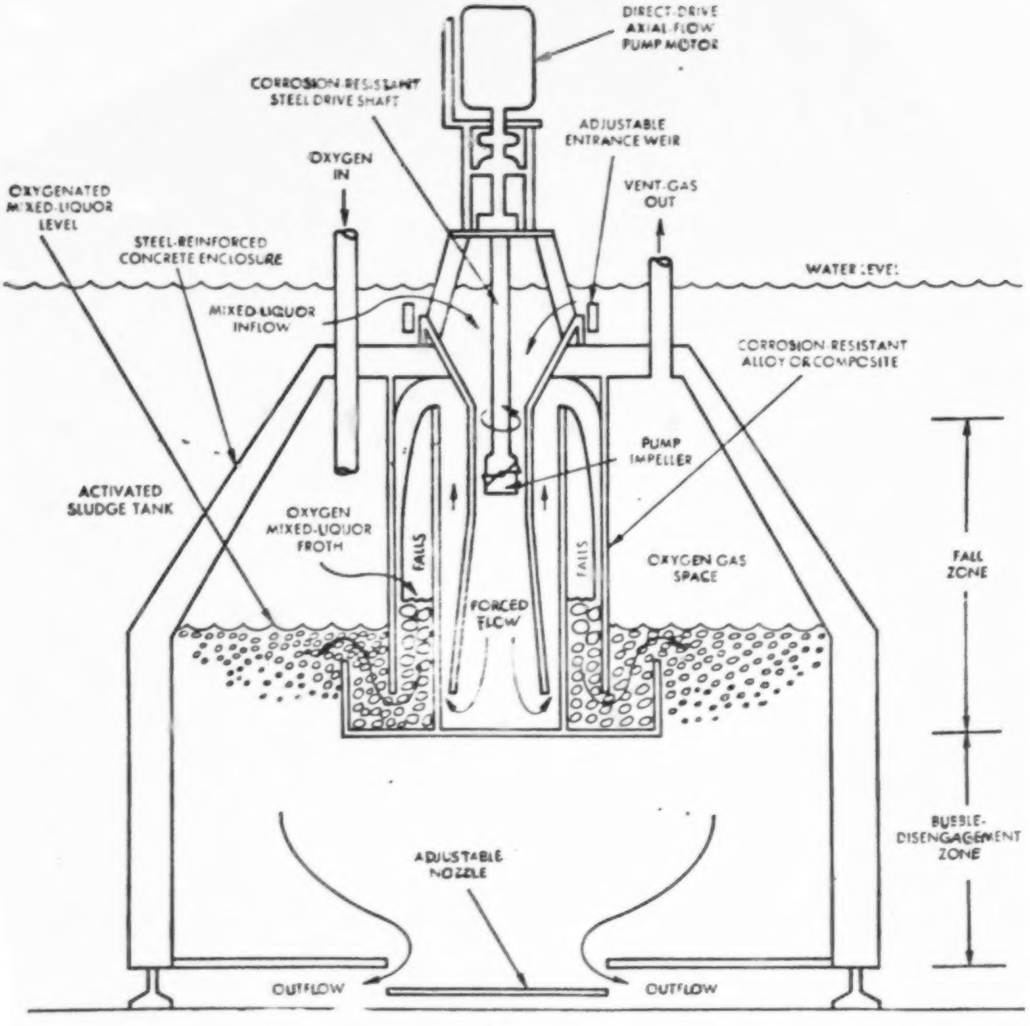
DIRECT-DRIVE AXIAL-FLOW PUMP MOTOR
CORROSION-RESISTANT STEEL DRIVE SHAFT
ADJUSTABLE ENTRANCE WEIR
OXYGEN IN
VENT-GAS OUT
OXYGENATED MIXED-LIQUOR LEVEL
STEEL-REINFORCED CONCRETE ENCLOSURE
WATER LEVEL
MIXED-LIQUOR INFLOW
CORROSION-RESISTANT ALLOY OR COMPOSITE
PUMP IMPELLER
ACTIVATED SLUDGE TANK
OXYGEN MIXED-LIQUOR FROTH
FALLS
FALLS
FORCED FLOW
OXYGEN GAS SPACE
FALL ZONE
BUBBLE-DISENGAGEMENT ZONE
ADJUSTABLE NOZZLE
OUTFLOW
OUTFLOW

Figure 34. Open-Tank Modular Oxygen Unit, Wayne, New Jersey (From Ref. 4)

aeration gases. However, while these gases are being dissipated, personnel should not smoke, or breathe the vented gases.

To prevent problems within the reactor, a dissolved oxygen probe should be in the liquid, as a guide to regulating the oxygen supply flow, as shown in the diagrammatic version of an open-tank single-stage reactor (Figure 32). The dissolved oxygen meter should be connected to an alarm system to inform the operator if the dissolved oxygen drops below 0.5 mg/l. If the alarm does not activate or the oxygen feed supply is not increased when the dissolved oxygen level drops, methane and sulfides will be formed. When the oxygen feed is turned back on, the combustible conditions will be worse for a short period because of the enriched oxygen in the atmosphere. If ignition occurs, an enriched system will be subject to more severe explosion and combustion effects. Once the methane is vented to the atmosphere, conditions would return to normal.

J. RETURN ACTIVATED SLUDGE SYSTEMS

Return Activated Sludge (RAS) systems are mainly completely closed all the way. Their flow passages are usually all below the surface or enclosed. A standard RAS removal system with single tanks is shown in Figure 35. With open tanks (as in Figure 35) there is little chance of problems.

Figure 36 shows a multiple tank arrangement which is an entirely different situation. Here multiple return activated sludge lines enter a common wet well where gases could be created. If return sludge were allowed to accumulate in a common wet well, the material could go septic and produce combustible gases. This septicity can be caused by improper removal of the material and can be transferred back to the aeration reactor. Figure 37 illustrates proper operating levels from a return activated sludge wet well with dual pumps.

K. SAFETY CHECK LIST FOR OXYGEN AERATION REACTORS

The following are items to be checked for safe operation:

1. Check for proper dissolved oxygen in liquid.
2. Check for proper mixing rate of tank contents.
3. Check for proper atmospheric conditions in an enclosed tank:
    a. Oxygen content
    b. Atmospheric pressure under cover
    c. Absence of combustibles
4. Check for proper primary influent flowrate.
5. Check for proper return activated sludge flowrate.

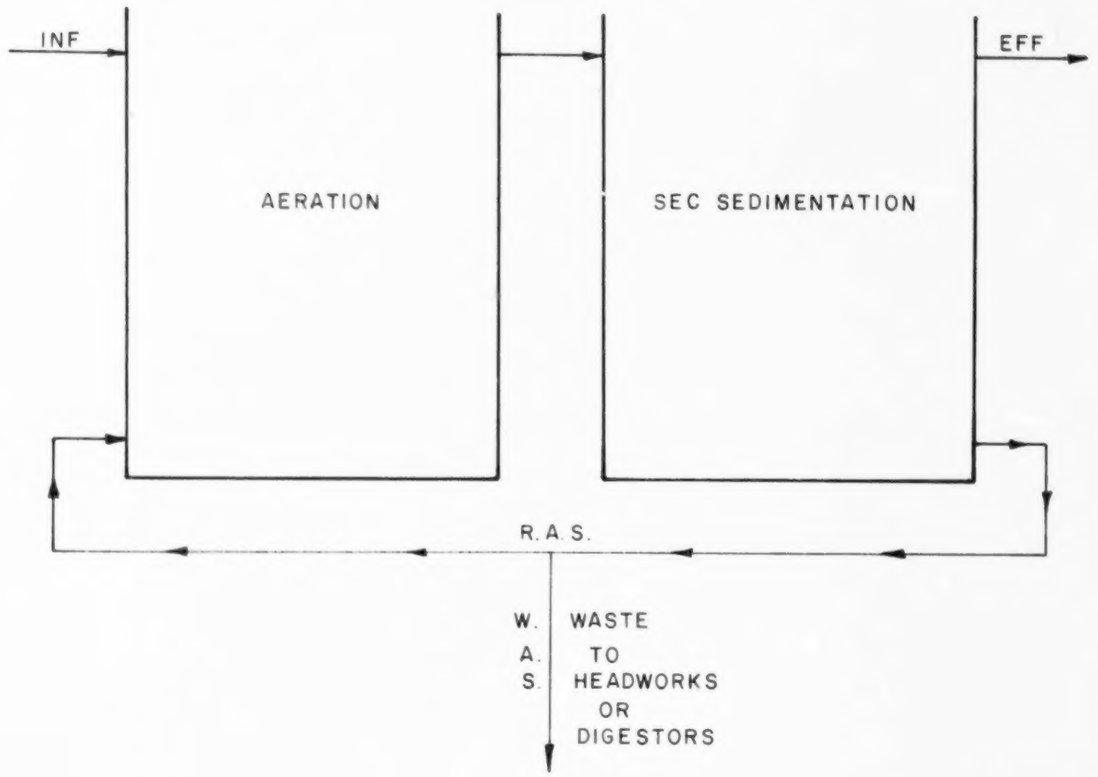
INF
AERATION
SEC SEDIMENTATION
EFF
R.A.S.
W.
A.
S.
WASTE
TO
HEADWORKS
OR
DIGESTORS

Figure 35. Return Activated Sludge Schematic-Single Tank

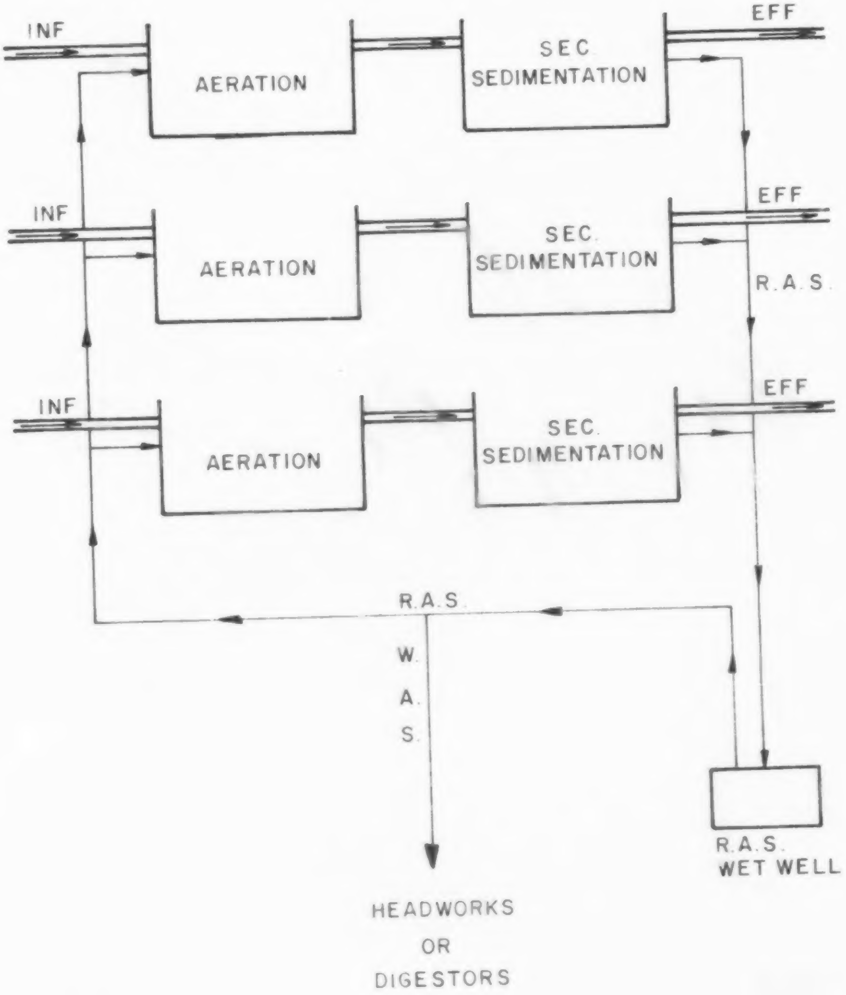
INF
AERATION
SEC.
SEDIMENTATION
EFF
INF
AERATION
SEC.
SEDIMENTATION
EFF
R.A.S.
INF
AERATION
SEC.
SEDIMENTATION
EFF
R.A.S.
W.
A.
S.
R.A.S.
WET WELL
HEADWORKS
OR
DIGESTORS

Figure 36. Return Activated Sludge Schematic
Multiple Tanks

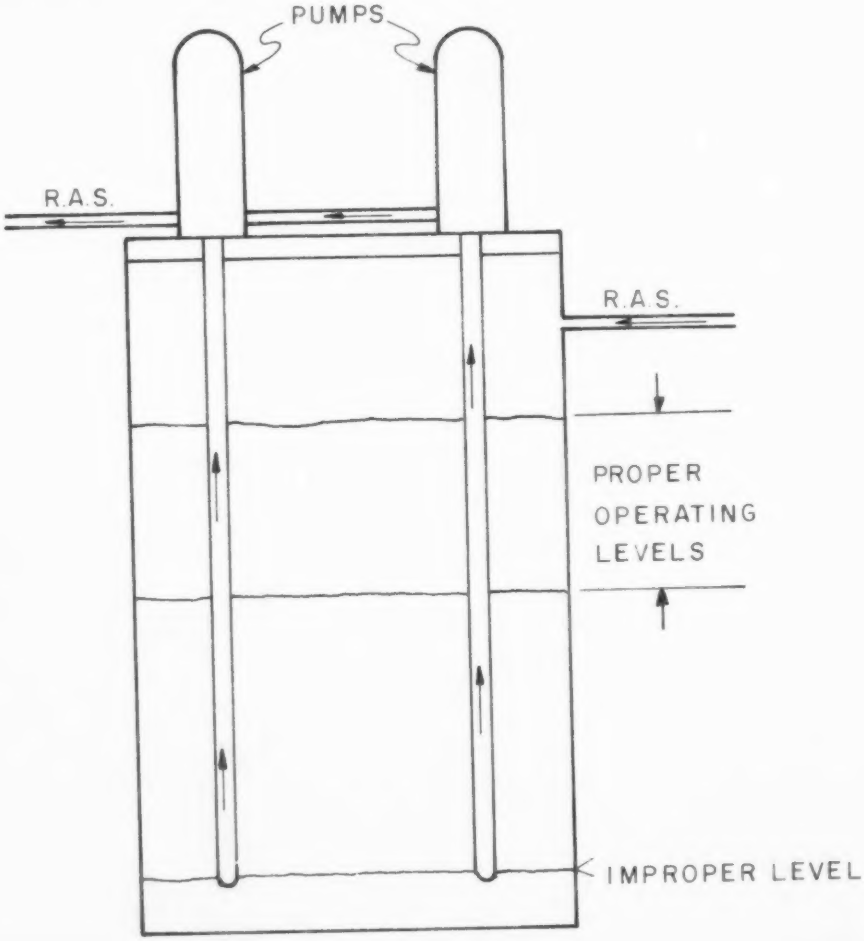
PUMPS
R.A.S.
R.A.S.
PROPER OPERATING LEVELS
IMPROPER LEVEL

Figure 37. Return Activated Sludge Wet Well

6. Check that no overheating occurs in motors driving mixers, blowers, and/or compressors.

7. Check for proper oxygen inflow and report any oxygen flow malfunction (e.g., stoppage, poor control, etc.) to operators of oxygen supply for correction.

NOTE: The above basic check list items are needed regardless of the type of oxygenation system installed. The user should make additional safety checks, appropriate to the specific oxygenation system in use, subsidiary items to the above.

L. REFERENCES

1. Remus, G., D. Suhre and G. Hubbell: "Detroit Aims for Savings With Pure Oxygen Aeration," Paper to WPCF Conference, San Francisco, CA, October 1971.

2. Brenner, R. C.: "EPA Experiences in Oxygen-Activated Sludge," EPA Advanced Waste Treatment Research Laboratory, Cincinnati, Ohio, October 1973.

3. Jenkins, J., R. Gozikowski, T. Roby, R. Morrison and P. Gilliland: "Performance of Pure Oxygen in Activated Sludge Treatment," In: Proceedings of the Symposium on New Trends in Water and Sewage Treatment Using Pure Oxygen and Ozone, Denver, CO, Bureau of Reclamation, October 1974.

4. "Unique New Secondary Oxygen Treatment System for Effluent," Paper Trade Journal, 5 August 1974.

III. TREATMENT OF INDUSTRIAL WASTES

When oxygen aeration is used in the treatment of highly concentrated industrial wastes, safety considerations may assume greater importance than in the case of normal domestic sewage. Table 3 illustrates various types of industrial waste products, both organic and inorganic, that could be discharged to a municipal treatment facility.

The industrial waste discharges may contain a wide variety of chemical compounds, many of them high in BOD and COD, with some of the inorganics poisonous to biological treatment processes. Further, times and amounts of the discharges are related to industrial factors such as manufacturing processes, operating shifts, with unforeseeable overloads, process upsets and other abnormalities. In contrast, diurnal and seasonal variations in the strength and flowrate of normal domestic sewage are quite predictable. Therefore, the operator must be much more watchful for circumstances which could lead to unsafe conditions when industrial sources are known to be discharging into a collection and treatment system.

Section-by-section, this chapter (III) parallels the preceding chapter (II) which dealt with the treatment of primarily domestic sewage. An effort has been made to avoid duplication of text material, although many of the illustrations are repeated to make this chapter self-contained.

A. PLANT INFLUENT STATION

1. Enclosed Headworks

Inadequate designs and poor operating practices become more readily apparent when handling high concentrations of industrial wastes compared to domestic wastes. Waste products that are readily settleable would cause severe problems in an enclosed headworks as indicated in Figure 38. Deposits would immediately produce hazardous gases that could be transmitted throughout the treatment chain. Figure 39 illustrates a condition of design and operation that can more easily and safely handle these types of products.

In addition to the products that are settleable, industrial waste products that are in solution offer great potential for hazardous conditions. In Figure 38 there are no means of detection or preclusion of potential production of hazardous materials. Figure 39 includes devices which enable the operator to perform the job properly and safely.

TABLE 3. INDUSTRIAL WASTE CHARACTERISTICS AND TREATABILITY

Source of Industrial Waste	Possible Adverse Effects on Environment	Type of Pretreatment Indicated	Biological Stabilization Practical
Organic			
Beverage Manufacturing	Oxygen depletion Suspended solids	Aeration Aeration	Yes Yes
Canneries	Oxygen depletion	Sedimentation	
Cereal Processing	Oxygen depletion	Aeration	Yes
Cosmetics	Toxicity, color, oils and greases	Grease separation Aeration	Yes
Fertilizers	Aquatic plant growth excessive	Sedimentation Neutralization	Yes
Foods (general)	Oxygen depletion	Aeration	Yes
Laundries	Alkalinity Oxygen depletion Foam production	Neutralization Aeration	Yes
Meat packing and processing	Oxygen depletion	Aeration Sedimentation	Yes
Milk and products	Oxygen depletion	Aeration Emulsion breaking Neutralization Grease separation	Yes
Paints	Color, suspended solids Oils and greases Oxygen depletion		
Paper	Suspended and dissolved solids, oxygen depletion, color	Aeration and sedimentation Screening	Yes
Pesticides	Toxics Oxygen depletion	Aeration	Partially

TABLE 3. INDUSTRIAL WASTE CHARACTERISTICS AND TREATABILITY (Continued)

Source of Industrial Waste	Possible Adverse Effects on Environment	Type of Pretreatment Indicated	Biological Stabilization Practical
Petroleum	High salt content Oils and greases	Grease separation Grit removal Aeration	Partially
Pharmaceuticals	Toxic Oxygen depletion	Aeration	Partially
Plastics	Toxic Oxygen depletion	Sedimentation Aeration	Partially
Rubber	Dissolved solids Toxic	Sedimentation	Partially
Sugar	Oxygen depletion Suspended solids	Screening Aeration Sedimentation	Yes
Tanning	Toxicity, color Suspended solids Oxygen depletion	Screening Bleaching Sedimentation Aeration	Yes
Textiles	Toxicity, color Suspended solids Oxygen depletion	Screening Aeration Sedimentation Bleaching	Yes
Wood products	Toxicity, color Suspended solids Oxygen depletion	Screening Bleaching	Yes
Wool processing	Oxygen depletion Oil and grease Alkalinity	Grease separation Grit removal Neutralization	Yes
Inorganic			
Carbon products	Suspended solids Toxicity	Filtration	No

TABLE 3. INDUSTRIAL WASTE CHARACTERISTICS AND TREATABILITY (Concluded)

Source of Industrial Waste	Possible Adverse Effects on Environment	Type of Pretreatment Indicated	Biological Stabilization Practical
Brass	Alkalinity Suspended solids	Neutralization Sedimentation	No
Metal fabrication	Oil and grease Suspended solids Toxicity	Grease separation Sedimentation	No
Metal Processing	Toxicity, color Dissolved and Suspended solids	Grease removal Neutralization Aeration Sedimentation	No
Mining	Suspended solids Toxicity, acidity	Sedimentation Neutralization	No
Photographic work	Toxicity Dissolved solids	Neutralization	No
Pigments and dyes	Color, toxicity Suspended solids	Bleaching Sedimentation	No
Radioisotopes	Toxicity Radioactivity	Ion exchange	No

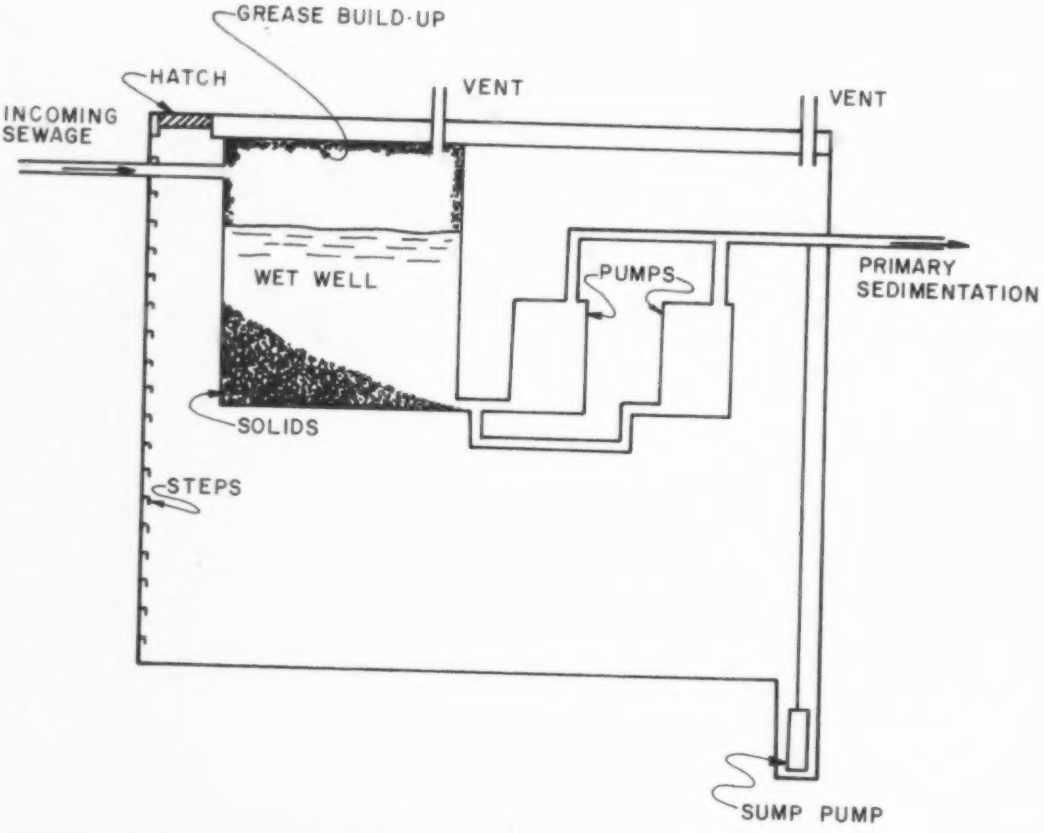
GREASE BUILD-UP
HATCH
VENT
VENT
INCOMING SEWAGE
WET WELL
PUMPS
PRIMARY SEDIMENTATION
SOLIDS
STEPS
SUMP PUMP

Figure 38. Enclosed Headworks - Inadequate Design

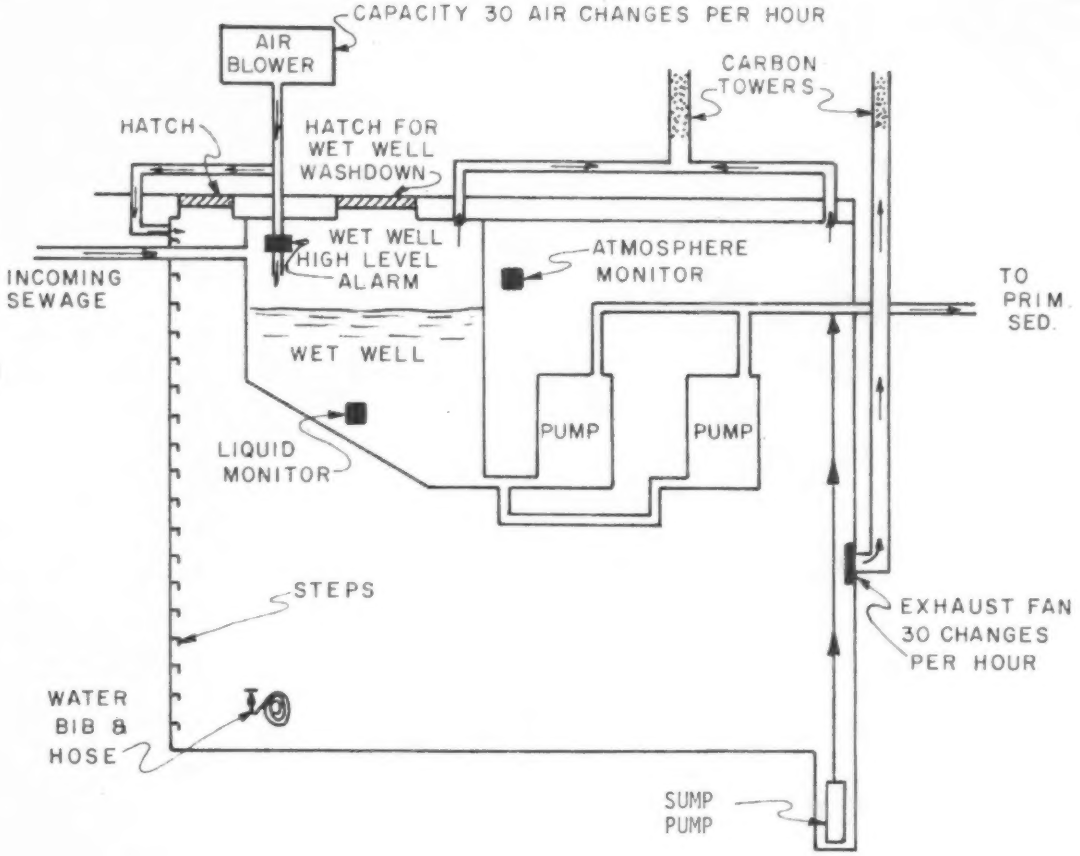
CAPACITY 30 AIR CHANGES PER HOUR
AIR BLOWER
CARBON TOWERS
HATCH
HATCH FOR WET WELL WASHDOWN
WET WELL HIGH LEVEL ALARM
ATMOSPHERE MONITOR
INCOMING SEWAGE
TO PRIM. SED.
WET WELL
LIQUID MONITOR
PUMP
PUMP
STEPS
EXHAUST FAN 30 CHANGES PER HOUR
WATER BIB & HOSE
SUMP PUMP

Figure 39. Enclosed Headworks - Adequate Design

2. Open Headworks

Similar to the open headworks discussed in Chapter II, an open headworks receiving industrial waste is a safer environment. However, any material received which has good settling characteristics can cause problems in a poorly designed and operated headworks section. Settleable material can produce gases that can be transmitted into the downstream treatment units if not handled properly. This is evidenced by the condition shown on Figure 40.

3. Alarm Monitoring (Open and Enclosed Headworks)

Devices should be used to monitor the following:

1. Atmosphere
   - Methane--explosive
   - Sulfide Gas--toxic
   - Hydrocarbon--explosive
2. Liquid
   - Dissolved Oxygen--anaerobic
   - Hydrocarbon--potentially explosive

B. PRIMARY SEDIMENTATION

1. Enclosed Tank

An enclosed primary tank handling high concentrations of industrial waste products, can cause severe problems if not designed and operated properly.

In reviewing the industrial waste (Table 3), all materials that are settleable offer continual potential problems. Unlike domestic wastewater, high suspended solids waste of industrial origin does not enter the treatment plant at a continuous uniform concentration. There may be certain hours during a day where concentrations are ten times as high as at other time periods. The operator must be constantly alert to this fact. Such changing load conditions require the removal of this material from the primary tank within a specified time, namely, the time to produce hazardous gases in the primary sludge blanket. Depending on the type of waste being handled and total in-sewer detention time, this could be anywhere from 1 hour to 3 hours.

If production of hazardous gas is allowed to occur in enclosed primary tanks, the atmosphere between the water surface and the cover becomes a gas storage unit. This gas can then be easily transmitted downstream into the aeration system. The condition shown in Figure 40 can be caused by the following:

1. Improper sludge pumping schedule
2. Slow collector flight speed

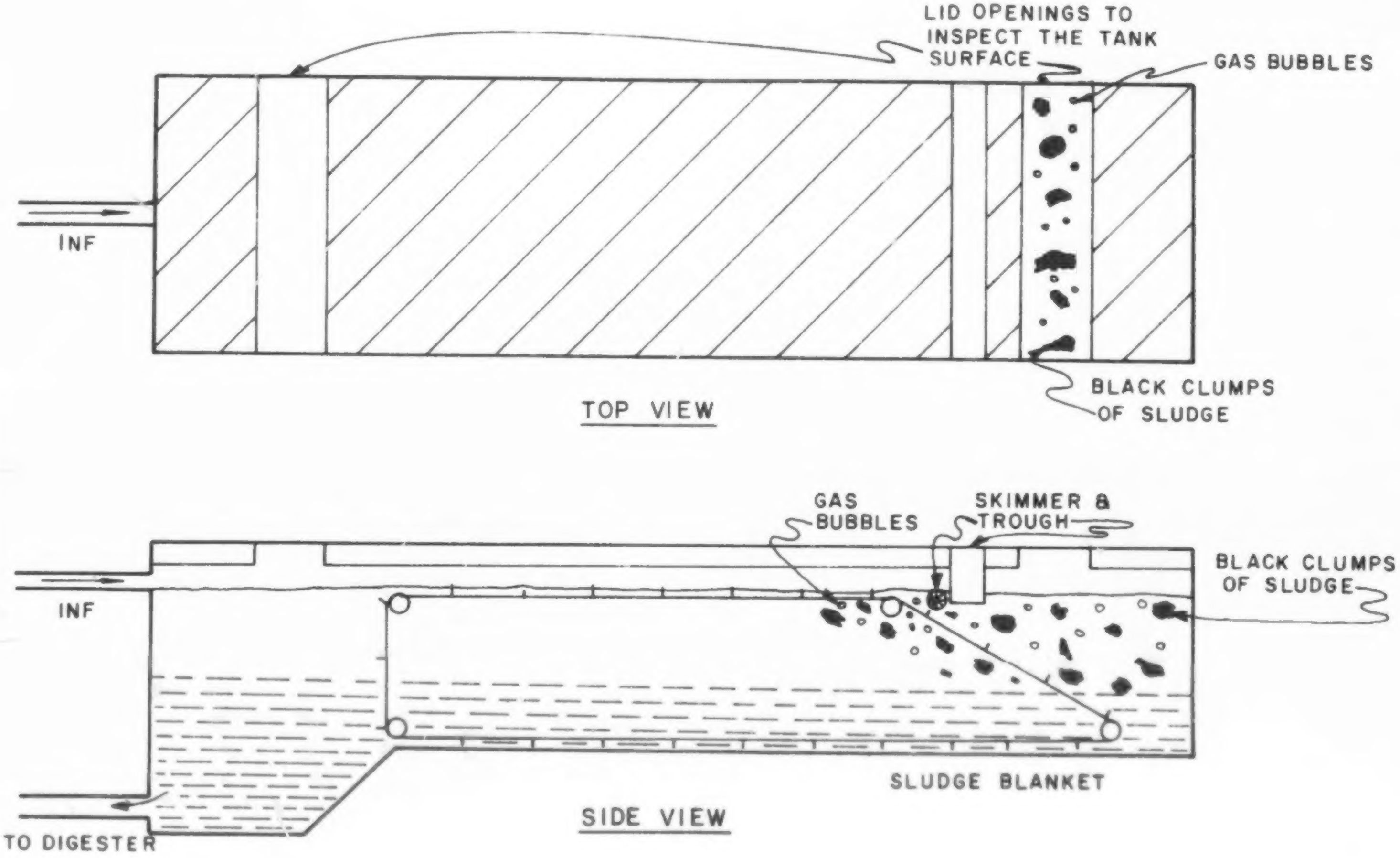
LID OPENINGS TO INSPECT THE TANK SURFACE
GAS BUBBLES
INF
BLACK CLUMPS OF SLUDGE
TOP VIEW
GAS BUBBLES
SKIMMER & TROUGH
BLACK CLUMPS OF SLUDGE
INF
SLUDGE BLANKET
TO DIGESTER
SIDE VIEW

Figure 40. Rectangular Enclosed Primary Sedimentation Tank-Showing Signs of Sludge Decomposition

3. Primary tank too small
4. High sludge blanket
5. Anaerobic supernatant recycle, if any

Figure 40 also illustrates a lack of proper operation and detection equipment. Figure 41 illustrates a proper system. This is extremely important in a system handling industrial waste because of the unpredictable constantly changing load conditions, in constrast to domestic sewage loads which are relatively predictable from one day to another.

2. Open Tank

Although an open primary tank offers little chance for the transmission of gases, due to storage under the cover, improper operating practices may still cause problems.

High sludge blanket conditions can produce hazardous gases. Although most of the gases will pass into the open atmosphere, some will be contained in the primary effluent. This, of course, will be immediately transmitted into the aeration tank.

All operating precautions recommended in the "Enclosed Tank" discussion should also be applied for open tank systems.

3. Alarm Monitoring (Open and Enclosed Tanks)

Devices should be used to monitor the following:

1. Atmosphere
    - Methane--explosive
    - Sulfide Gas--toxic
    - Hydrocarbon--explosive
2. Liquid
    - Dissolved Oxygen--anaerobic
    - Hydrocarbon--potentially explosive

C. OXYGEN AERATION ACTIVATED SLUDGE REACTOR

1. Enclosed Tank

All operating procedures listed in Chapter II for domestic wastes also apply here. However, the operator must be alert to the fact that the potential for hazardous materials entering the enclosed aeration tanks is much greater when handling industrial wastes.

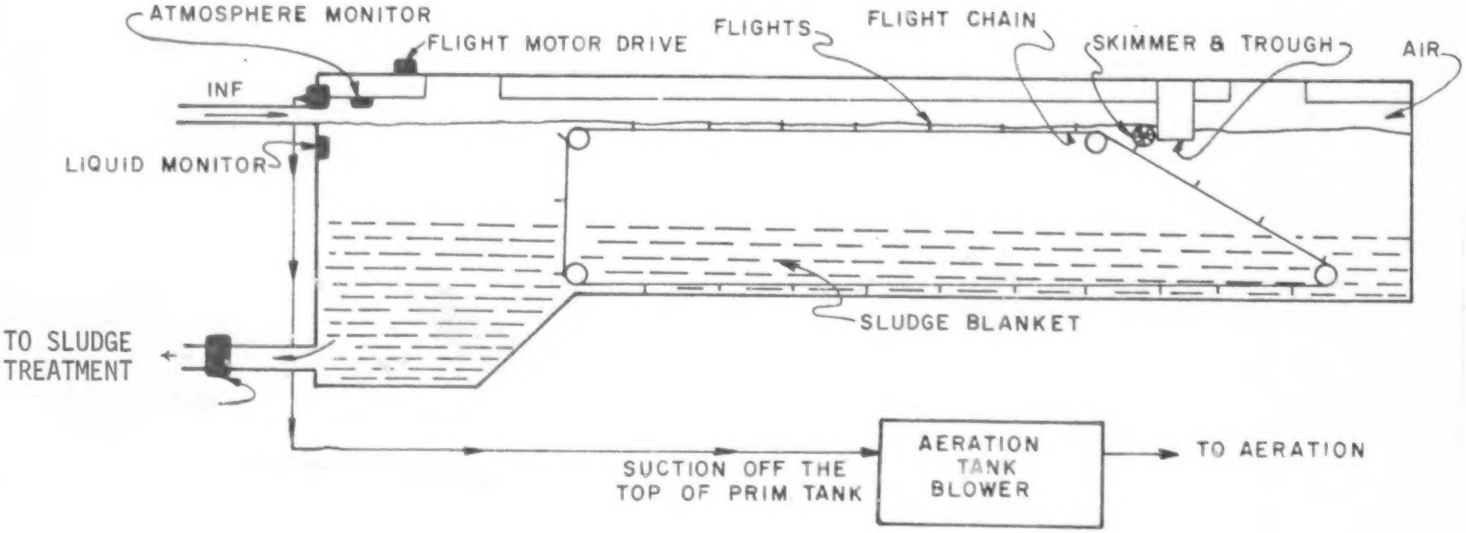
ATMOSPHERE MONITOR
FLIGHT MOTOR DRIVE
FLIGHTS
FLIGHT CHAIN
SKIMMER & TROUGH
AIR
INF
LIQUID MONITOR
SLUDGE BLANKET
TO SLUDGE TREATMENT
SUCTION OFF THE TOP OF PRIM TANK
AERATION TANK BLOWER
TO AERATION

Figure 41. Rectangular Enclosed Primary Sedimentation Tank With Submerged Outlet

The most significant problem in this component is oxygen depletion. An industrial waste material having an extremely high immediate oxygen demand can enter the system. If this is allowed to occur undetected, anaerobic conditions may develop.

2. Alarm Monitoring-Enclosed Reactor

Devices should be used to monitor the following:

1. Atmosphere
    - Methane--explosive
    - Sulfide--toxic
    - Hydrocarbon--explosive
    - Oxygen--combustion supporting
2. Liquid
    - Dissolved Oxygen--anaerobic
    - Hydrocarbon--potentially explosive

3. Open Tank

Again, the open tank is inherently safer than a closed one. Operation is safer with gases passing to the atmosphere rather than being collected in an enclosure. If unit processes upstream of an open reactor treating industrial wastes are operated poorly, there is litte effect on the aeration tank itself from a safety standpoint. This becomes very evident when comparing the conditions in Figure 42 (enclosed tank) and Figure 43 (open tank).

4. Alarm Monitoring-Open Reactor

Devices should be used to monitor the following:

1. Atmosphere - none
2. Liquid
    - Dissolved Oxygen

D. RETURN ACTIVATED SLUDGE SYSTEM

All conditions discussed in Chapter II relative to return activated sludge also apply to a system handling industrial waste.

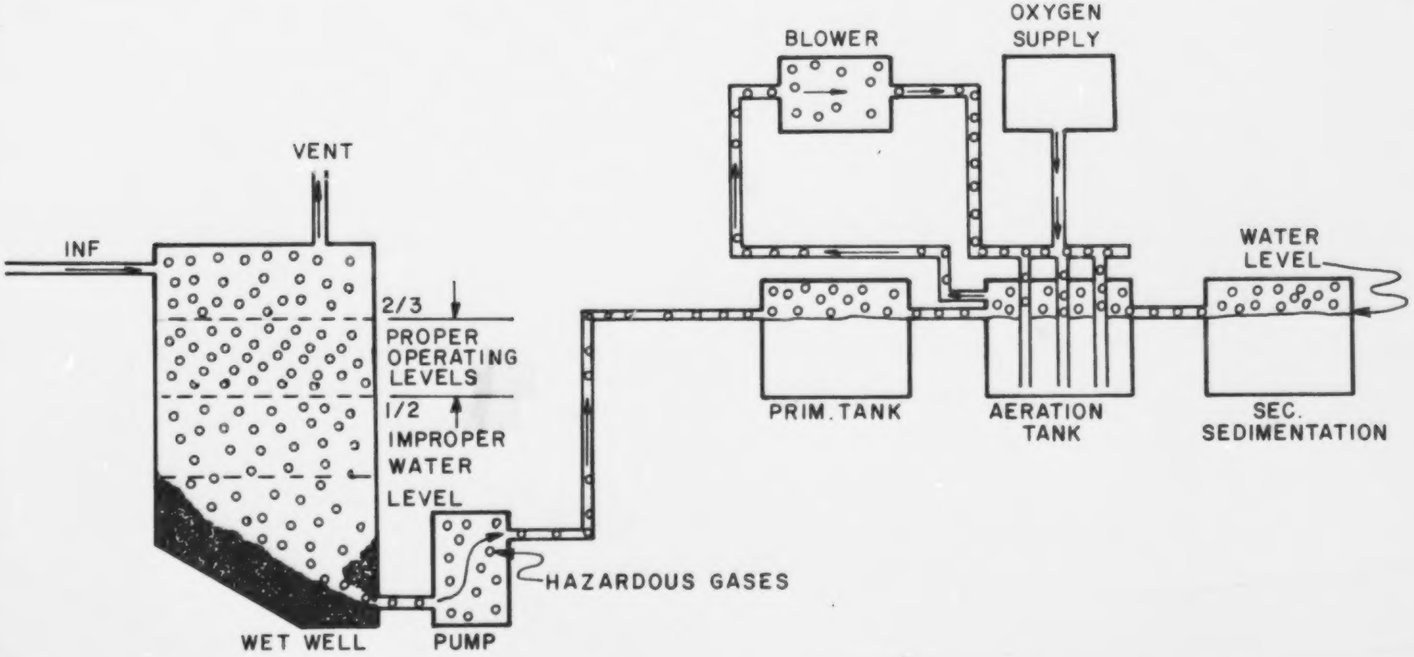
BLOWER
OXYGEN SUPPLY
VENT
INF
2/3
PROPER OPERATING LEVELS
1/2
IMPROPER WATER LEVEL
WATER LEVEL
PRIM. TANK
AERATION TANK
SEC. SEDIMENTATION
HAZARDOUS GASES
WET WELL
PUMP

Figure 42. Pump Cavitation Condition With Enclosed Tanks

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
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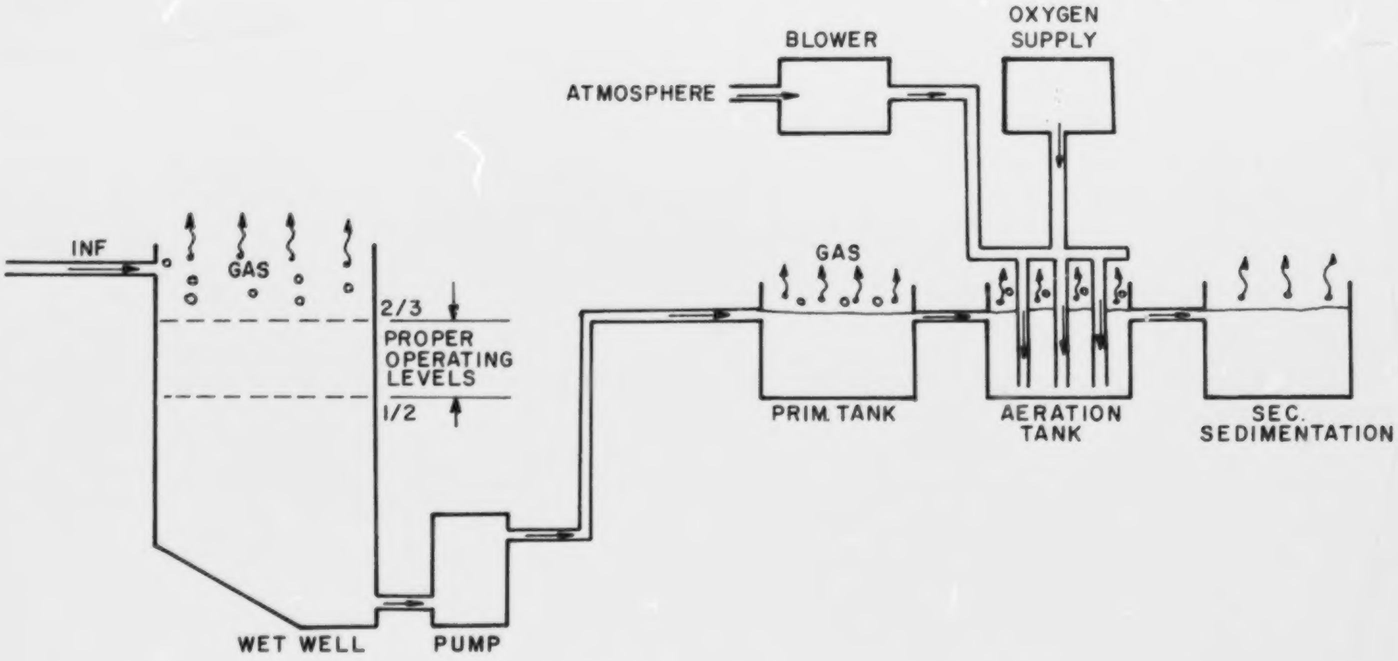
OXYGEN SUPPLY
BLOWER
ATMOSPHERE
INF
GAS
2/3
PROPER OPERATING LEVELS
1/2
GAS
PRIM. TANK
AERATION TANK
SEC. SEDIMENTATION
WET WELL
PUMP

Figure 43. Proper Pumping Conditions With Open Tanks

IV. OXYGEN SYSTEM

A. OXYGEN AND LIQUID OXYGEN

1. Properties

Gaseous oxygen is colorless, odorless, tasteless and nonexplosive. The liquid, at -297.9 F under 1 atmosphere, is light blue and transparent, is non-shock sensitive, and will not decompose. In either gaseous or liquid form, oxygen is a strong oxidizer which vigorously supports combustion. Most common solvents are solid at liquid oxygen temperatures. Liquid oxygen is completely miscible with nitrogen and methane. Light hydrocarbons are usually soluble in liquid oxygen. The major physical properties of oxygen are given in Table 4.

2. Hazards

The principal hazards associated with the handling of oxygen are:

- Freezing injury by exposure of the body to the liquid or to cold gas
- Fire or explosion supported by liquid oxygen and oxygen gas
- Overpressurization caused by vaporization of small amounts of liquid to form large volumes of gas in inadequately vented equipment

a. Health Hazards - The very low temperature of liquid oxygen can cause a freezing injury if the liquid, or uninsulated piping containing it, contacts the skin or if the liquid is splashed into the eyes. Inhalation of very cold oxygen gas may cause some irritation to the upper respiratory tract. Oxygen gas is normally nontoxic, but long-term exposure to high purity oxygen at elevated pressures can adversely affect muscular coordination and power of attention.

b. Fire and Explosion Hazards - A material which burns in air, generally burns more violently and sometimes explosively in a high concentration of oxygen, while other materials not normally combustible in air and not usually thought of as fuels, e.g., some metals, industrial soot, dirt, can be ignited. Spills of liquid oxygen and subsequent enriched atmospheres of oxygen resulting from vaporization, can present great fire danger in the presence of a fuel, e.g., clothing. When mixed with liquid oxygen, all materials that burn represent explosion hazards.

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TABLE 4. PHYSICAL PROPERTIES OF OXYGEN

Property		English Units	Metric Units
Boiling point		-297.4 F	-183.0 C
Freezing point		-361 F	-218.3 C
Liquid density		9.53 lb/gal at -297.4 F	1.14 g/ml at -183 C
Vapor density (relative to standard temperature and air pressure)		1.105 at 32/32 F	
Critical pressure		737 psia	5.09×10^6 N/m^2 at -118.4 C
Critical temperature		-181.1 F	-118.4 C
Vapor pressure		37 psia at -280 F	2.55×10^5 N/m^2 at - 173 C
		167 psia at -240 F	1.15×10^6 N/m^2 at -151 C
		492 psia at - 200 F	3.39×10^6 N/m^2 at -129 C
		615 psia at -190 F	4.24×10^6 N/m^2 at -123 C
Coefficient of viscosity	Kinematic	0.17 centistokes at -297.4 F	
	Absolute		0.19 centipoises at -183.0 C

N/m^2 = 7.50×10^{-3} mm Hg = 9.87×10^{-6} std atm

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c. Overpressurization - Liquid oxygen trapped between two valves in an unrefrigerated pipe can cause the pipe to rupture violently since oxygen cannot be kept liquid if its temperature rises above the critical point (-181.1 F) regardless of the pressure. Similarly, loss of refrigeration may lead to storage tank rupture if the oxygen is not dumped or pressure is not relieved by suitable devices. The loss of vacuum in vacuum jacketed tanks can cause increased evaporation and failure of the venting system if the system is inadequate to sustain the extra load.

3. Materials of Construction

The materials of construction used in an air separation plant are subjected to a wide range of pressures and exposed to temperatures from about +500 F (for reactivation purposes) to -320 F (the temperature of liquid nitrogen). Careful attention must be given to the selection of materials which can withstand the special conditions of this service. The tensile strength of metals increases as the temperature decreases; however, as the temperature decreases, many metals become brittle and are subject to failure under shock or impact conditions. Equipment not specifically designed for cryogenic service should not be used until it is checked completely for conformance with the applicable specifications for the intended service.

In molecular sieve adsorber air separation installations, temperatures below -20 F are not encountered (unless one includes cryogenic oxygen supplies used as emergency standby in case oxygen production falters or is momentarily inadequate). In this type of air separator, one need not be concerned with low temperature embrittlement.

a. Metals - Some metals react violently with liquid oxygen under certain conditions. Titanium should be avoided in air separation systems since the reaction with liquid oxygen may propagate and completely consume the metal. In general, the use of carbon steel in oxygen service is restricted because it burns vigorously in high concentrations of oxygen and its ignition temperature decreases as pressure increases. In addition, the use of carbon steel is restricted to temperatures of -20 F and above. Carbon steel process piping with welded connections is used in molecular sieve air separation units in which low temperatures are not encountered and oxygen pressures are below 65 psig. Metals which can be used safely below -20 F are:

1. Aluminum
2. Stainless Steel - austenitic
3. Nickel steel alloy (9 percent)
4. Copper and copper alloys
    a. copper
    b. naval brass
    c. admiralty brass
    d. aluminum bronze
    e. cupro-nickel

5. Nickel and nickel alloys

   a. nickel
   b. René-41
   c. K-Monel
   d. Inconel X
   e. Hastelloy B

b. Non-metals - Non-metallic materials for use as gaskets, valve packing, must be carefully checked for acceptability. No substitution of materials should be made without the approval of the equipment supplier or other qualified engineering source. Non-metals which are usually considered to be acceptable are:

1. Tetrafluoroethylene polymer (TFE, Halon TFE, Teflon or equivalent)
2. Unplasticized chlorotrifluoroethylene polymer (Kel F, Halon CTF or equivalent)
3. Asbestos
4. Durabla

c. Insulation - To protect the cryogenic process streams from unnecessary heat input or to avoid exposure of personnel to extreme cold temperatures, low temperature process stream lines are insulated. For use on liquid oxygen lines or lines that may come in contact with liquid oxygen and on process lines colder than the condensing temperature of air, the insulation should be noncombustible. Process lines operating at temperatures above the air condensation point should be noncombustible or self-extinguishing. Weather protection should be applied to insulation. Usually acceptable insulation materials are cellular glass, glass wool, rock wool, and perlite.

B. OXYGEN SAFETY CHECKLIST

The following conditions should be checked to prevent personnel injury and/or equipment damage.

1. All personnel who may be involved in the transfer, storage, and handling of liquid or gaseous oxygen shall be informed of the properties of liquid and gaseous oxygen, the dangers involved, and the safety precautions required
2. Approved goggles and face shields, protective clothing, and gloves and boots should be worn if handling or transferring liquid oxygen. Clothing must be free of grease and oil.
3. No smoking or open flames should be permitted within 50 feet of oxygen loading or unloading areas or of oxygen storage tanks, or in the vicinity of oxygen plants. Appropriate signs shall be posted. Care should be taken that tank vents that are not in the immediate loading vicinity are also posted.
4. Adequate ventilation must be provided. Liquid oxygen shall be handled in well ventilated areas only. Work should not be performed in an atmosphere containing more than 25 percent oxygen.

5. Allow time for any oxygen absorbed in clothing, from liquid-oxygen storage or handling areas, to reduce to normal atmospheric composition before you smoke or approach sources of ignition.
6. Do not use fire blankets in fighting fire in an oxygen-rich atmosphere.
7. Exercise extreme caution to prevent any oils, greases, fuels, or combustible materials from coming into contact with liquid oxygen. Degrease all tools and metals before using with liquid oxygen.
8. Liquid oxygen storage units may not be placed on macadam, asphalt, or any other oil base surfaces. Concrete pads are desirable; clean gravel or stone surfaces are satisfactory.
9. All tanks, containers, piping, etc., for use in an oxygen system must be suitably cleaned before the system is put into service. All mill scale, rust, dirt, weld slag, oils, greases, and other organic material must be removed.
10. Use care to prevent the accumulation of moisture in lines, valves, traps, etc., to avoid freezing, plugging, subsequent ruptures, and the trapping of liquid oxygen in unvented sections of the system.
11. Inspect safety showers and personal protective equipment periodically and prior to any operation involving liquid oxygen.
12. Parts of the body that have been contacted by liquid oxygen should be treated by flushing the affected area with water. Do not rub or touch the injured area. After flushing, obtain medical attention.

C. GENERAL OXYGEN PRODUCTION PLANT CONSIDERATIONS

1. Site Criteria

If the oxygen production facility is to be constructed near an already existing sewage treatment facility there may be disadvantages since the criteria for locating a sewage treatment facility are not necessarily the same as those for an air separation plant. Generally, however, the site will be in an industrial, semi-rural, or rural area, not in a residential or commercial zone. Specific siting considerations are listed below.

a. Inlet Air Quality - The quality of the inlet air is usually a very important consideration in determining the location of a cryogenic air separation plant. The plant cycle and equipment, especially as to sizing of clean-up devices such as adsorbers, will be affected. The adsorption air separation plants are not as sensitive to hydrocarbon or CO_2 contaminants in the inlet air as is a cryogenic air separation unit. The molecular sieve bed will adsorb these contaminants along with N_2 and vent them during the blowdown and purge cycle.

b. Terrain - The land should support heavy equipment without fear of ground settling or excessive vibration. The soil should be able to safely tolerate an accidental liquid oxygen spill.

c. Hazards from Surroundings - There should be no potential fire or explosion hazards from within the sewage treatment plant or from existing or forecast nearby industrial operations.

d. Effect of Plant on Surroundings - An accidental liquid oxygen spill and cryogenic fog should not endanger neighbors, industrial operations, road, and sewage systems.

e. Adequate Space - The plant site should contain adequate space for proper oxygen storage and transfer, maintenance area separate from operating area, space for removal of major components, area for plant traffic, and a proper facility for oxygen or other cryogenic liquid disposal.

f. Fire Protection - Time required to obtain outside assistance in an emergency must be considered along with the quality of the equipment and personnel.

2. Plant Layout

Plant layout is concerned with the various factors that must be considered in the arrangement of equipment for the safety of operation and maintenance. The following paragraphs describe the facilities and equipment which must be a part of safe design practices and procedures.

a. Accessibility - The layout of the equipment must permit safe operator accessibility to the equipment and to all valves and controls required for normal and emergency operations and maintenance.

b. Personnel Protection - As in all industrial plants, guard rails, platform gates, and ladder cages should be provided for elevated areas. Protective shields should be considered where natural isolation of equipment, valves, or piping is difficult or impractical and an explosion hazard may exist.

c. Oxygen Lines and Manifolds - Oxygen lines should not be placed in the same pipe rack with fuel lines. The use of valve pits, trenches, confined or enclosed locations for oxygen lines is hazardous and should be avoided. Trenches can collect oil and debris and are potential oxygen-enriched or oxygen-deficient areas. If valve pits cannot be avoided, forced ventilation, an alarm system, and periodic maintenance are recommended.

Oxygen manifolds should not be located within 20 feet of cylinders of combustible gases unless they are separated by a fire-resistive partition.

d. Vents, Drains, and Defrost Stacks - All vents and drains from air separation equipment should be located outside enclosures and buildings. Liquid oxygen drains should be installed above ground to prevent liquid oxygen accumulation in event of a leak. Precautions should be taken to prevent liquid oxygen from entering floor drains. Trapped lines should be avoided to prevent the possible accumulation of any contaminants to their lower explosion limit.

e. Oxygen Concentration - All areas frequented by personnel during normal plant operation and maintenance, such as gas venting, liquid drainage, and equipment repair, should be located or ventilated so that the normal oxygen content in air will exist.

f. Oxygen Compression Equipment - The oxygen compression equipment should be as isolated as possible with respect to the rest of the plant to minimize personnel exposure and equipment damage in case of an accident.

g. Air Compressor - The air compressor intake should be located away from the various vents and blowdowns of the air plant and gas releases from neighboring plants. This is to prevent drawing oxygen-enriched air into an oil-lubricated compressor and the ingestion of gaseous impurities to a cryogenic plant in amounts greater than a plant capability to remove them. If possible, the air intake should be on the upwind side of the plant.

h. Maintenance and Storage - Maintenance and storage areas should be separate from operating areas. A separate storage room should be provided for combustible supplies such as oils, lubricants, and paints.

i. Product Storage and Loading Areas - Product storage should normally be located near the periphery of the air separation plant layout. Adequate space should be provided for the maneuvering of vehicles to be accommodated. Concrete pads or other noncombustible surfacing should be used (not asphalt) where liquid oxygen storage and transfer lead to the possibility of liquid oxygen spills. Storage sites must have good drainage to allow spills to flow and disperse to encourage rapid evaporation. Paving should be sloped to guide the flow of a spill and curbing should be used to prevent flow toward process equipment or sewers.

j. Location of Electrical Equipment - Explosion proof electrical equipment is not required in an air separation plant, but electrical units should not be located in areas where they may be subjected to high oxygen concentrations. Pumps, motors, and other electrical equipment that must be placed near the cold box or other sources of oxygen, should be located to have good ventilation.

k. Emergency Equipment - Emergency plant lighting, plant emergency trip stations, suitable exit doors, adequate fire protection, alarm systems, and equipment isolation valves are design safety features that should be considered.

3. Applicable Equipment Codes

Design of equipment in air separation plants should be in accordance with applicable codes listed.

1. ASME Boiler and Pressure Vessel Code, Section VIII, "Unfired Pressure Vessels"
2. American Standard Codes for Pressure Piping, Sections as applicable for the pressure and temperature of service
3. Applicable State and Local Codes

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4. Oxygen Piping

a. General Considerations - Oxygen piping systems should be designed and installed in accordance with ANSI B31.3 "Petroleum Refinery Piping." Additional rules must be observed based upon the following observations made from a study of the past history of fires in oxygen service: (1) There has been no indication of ignition occurring in clean carbon steel or stainless steel systems sized for normal pressure drop unless precipitated by the introduction of a foreign substance. (2) There have been several instances where ignition was indicated in carbon steel and stainless steel systems operating at, or near, sonic velocity. Friction from high-velocity particles is considered to be the source of ignition. (3) Copper, brass, and nickel alloys have the characteristic of melting at temperatures below their ignition temperature. This characteristic makes them extremely resistant to ignition in oxygen service. Once ignited, these materials exhibit a much slower rate of burning than carbon or stainless steels.

A consideration of the above considerations has led to the basic design rules listed below.

1. Use of carbon or stainless steel piping in continuous or frequent flow circuits must be limited to velocity well below sonic. The maximum velocity for these materials has been established at 200 ft/sec to provide a significant margin below sonic and an economical limit for pressure drop.

2. Lines with velocities greater than 200 ft/sec shall be constructed of copper, brass, or nickel alloys.

3. Valves and piping continuously exposed internally to moist gas (dew point above -40 F) or atmospheric air shall be constructed of a non-corrosive material such as bronze, copper, brass, nickel alloys or stainless steel.

4. The 300 series stainless steels have a higher ignition temperature and are less susceptible to corrosion than the 400 series stainless steels. Therefore, when operating conditions require use of stainless steel, it shall be the 300 series.

5. Cleanliness is a prime requisite of all oxygen piping as well as nitrogen piping used for purging oxygen systems. Cost of achieving and maintaing cleanliness shall be considered in selecting the best materials. Therefore, stainless steel will normally be utilized in place of carbon steel for oxygen compressor interstage piping, discharge piping to the check valve and recycle piping to the throttle control valve, where operating pressures permit the use of schedule 10. Required cleanliness for welding operations is to be achieved by the following:

    (1) Backup rings shall not be used except for piping within a cold box up to and including the first flange outside the cold box.

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(2) The first root pass shall be with inert gas, shielded arc process (TIG or MIG).

(3) Unless the interior of each weld joint can be visually inspected, X-ray is required to verify absence of potentially loose metal. All field closure joints shall be X-rayed for this determination as well as for joint integrity.

Certain areas in oxygen piping systems require special attention because the gas velocity is known to approach sonic. These areas include vent systems, letdown systems, and compressor recycle systems. Where the pressure ratio across a valve in a vent or letdown is greater than 2, the pipe on the downstream side of the valve should be constructed of monel, copper, bronze, or brass, be one full line size greater in diameter than the upstream pipe, and should have a straight run of 10 pipe diameters to allow the gas to shock down before a bend (also of monel, copper, bronze or brass) or a silencer can be installed. For subsonic flow downstream of the valve, stainless steel pipe can be used. If the velocity is less than 200 ft/sec in a letdown, carbon steel pipe can be used. Downstream of the valve in a vent system, only noncorrosive materials should be used because of exposure to the atmosphere. Adequate supports should be provided where required for the thrust of vent systems.

The compressor recycle system is particularly critical because of the high flowrate, the conditions under which it is operated, and the potential damage from a fire in this area. The side entrance tee is considered a vulnerable area due to possible direct impingement of high velocity particles. For line sizes 6 inches and below, a monel tee should be used. For larger tees, the inside run of the tee should be lined with a 1/16-inch-thick rolled monel, ASTM B127, impingement plate. The plate should cover one-half the pipe circumference in the main run and shall fit tightly and continuously against the inner wall. Attachment shall be by continuous TIG weld along all edges to achieve a smooth bead. Potentially loose material or sharp edges are not permitted.

Orifice plate material shall be monel for velocities greater than 200 ft/sec through the orifice and stainless steel for lower velocities.

b. Underground Lines - Lines installed underground should be of welded or silver brazed joint construction. Lines should be adequately supported and the fill under the line well drained. If the lines are long, consideration should be given to expansion joints to compensate for the expansion and contraction due to temperature changes. Suitable external coating material should be used on the line to minimize ground induced external corrosion. Where underground lines pass under roadways, they shall be encased in suitable pipe sleeves that are vented to atmosphere.

c. Above Ground Lines - Lines installed above ground should be all welded or silver brazed joint connection and should be adequately supported. Flanges may be used at valves and similar piping components. If the lines are long, expansion joints or loops should be used to compensate for expansion and contraction due to temperature changes. A good external paint must be provided against the weather.

d. Shutoff Valves - Shutoff valves should be located at convenience points or branches of the lines to permit isolation for test purposes and for isolation in the event of a system failure. If the use point is not under the direct control of the air plant operators, or where, due to a long or extensive transmission system, there is exposure to rupture or damage from outside sources such as road repair, excavation, heavy equipment, etc., automatic shutoff valves should be installed immediately downstream of the last source of supply. This shutoff valve should be designed to close under either excess flow or low pressure conditions as would result in a major failure of the transmission system.

Piping systems should be adequately separated from external sources of heat, mechanical damage and excessive vibration. If carbon steel lines may be exposed through system failure or misoperation, to cyrogenic temperatures (for example, downstream of a liquid vaporization system) the design must include low temperature sensing devices to alarms and to shut down the operation.

e. Safety Valves and Rupture Disks - Safety valves should be included on all process and mechanical equipment as dictated by good design and the applicable codes and specifications. Material, capacity, and type of design must be compatible with the service intended. Particular attention should be given to the location of safety valves in the cold sections of the plant. Process safety valves must, of course, be provided to vent the full process flow in the event of a plant upset. Thermal relief valves must be provided on all vessels and sections of pipe not otherwise protected by safety valves and rupture disks, in which cryogenic liquids may be trapped by closing off valves.

Rupture disks should always be located in a warm zone or on a warm leg. Rupture disks are designed to break at a specific pressure at a specific temperature. The tensile strength of the disk, and thus the pressure at which it will rupture, is affected directly by the temperature. As the temperature is lowered, the rupture pressure may increase as much as 20 percent to 100 percent depending on the material used and the temperature to which it is cooled. Placing the safety head in a warm zone or on an adequately designed warmup leg will limit the temperature variations to that of the ambient condition or to minor process fluctuations.

Safety devices, once installed and placed in operation, should be inspected and tested periodically. Some valves, such as the process safety valves on the high- and low-pressure columns may blow from time to time due to process fluctuations or during startup and operation, therefore release pressure, reseating pressure and leakage are readily checked. Other valves, such as the thermal relief valves, may not be used from one year to the next. Under these conditions, it is possible for the valves to freeze due to accumulation of dirt and rust and thereby fail to operate properly.

5. Electrical Requirements

Air separation plants are not hazardous locations as defined and covered in Article 500 of the National Electrical Code (NFPA No. 70). (However, some plants may include specific areas or equipment which necessitate special consideration, e.g., a plant with a refrigeration system employing a hydrocarbon refrigerant, or one including an argon purification unit involving the use and handling of hydrogen). Therefore, general purpose or weatherproof types of wiring and equipment are acceptable depending on location. Applicable provisions of the National Electrical Code and local codes should be followed. In areas where high oxygen concentrations could be expected, electrical equipment with open or unprotected make-and-break contacts should be avoided. The simple expedient of locating electrical equipment away from areas where high oxygen concentrations may occur will eliminate any potential hazard. Wherever possible, electrical and control circuits, which are susceptible to fire damage, should not be routed through a fire hazard area.

6. Fire Protection

In addition to the use of portable carbon dioxide or dry powder extinguishers at strategic points, water hydrant and hoses should be provided at accessible locations with provision for an adequate water supply. Inside-of-buildings the application of fog nozzles with rigid fire hose has been found effective for air separation plant use.

Isolating valves located in oxygen lines between major plant areas or components can be a very valuable part of the fire protection system. These valves may be arranged for automatic operation based on pressure, or flow; or arranged for remote manual operation; or both.

7. Noise

The noise produced by air compressors and their drives, by expansion turbines, and by blow offs or vents can be a potential hazard to employees. The OSHA Act specifies exposure limitations which can be sustained without hearing protection. Application of noise reduction devices to existing equipment and protective devices for personnel should provide compliance with safety legislation.

8. Emergency Shutdown

It is usually advisable to provide at least one location (remotely situated and preferably out-of-doors) where all plant power may be cut off quickly in an emergency. Plant systems must be designed for fail-safe operation and to ensure that emergency shutdowns do not affect any part of the system so as to increase the hazard potential due to the shutdown. Plant personnel training should definitely include recommended actions to be taken in emergency situations.

D. AIR AND OXYGEN COMPRESSORS

1. General

Two major types of compressors are dynamic machines (which include axial and centrifugal compressors) and positive displacement machines (which encompass reciprocating, diaphragm, and rotary types). Subsections 2 through 5 apply to air compressors in general, while subsections 6, 7 and 8 relate specifically to oxygen service.

2. Dynamic Machines

Axial type compressors have commonly been used for the main air compressor on large tonnage oxygen plants, while centrifugal compressors have been widely used for the main air compressor duty as well as oxygen product and nitrogen recycle services. For both axial and centrifugal machines, careful consideration should be given to the performance characteristics as compared to the expected plant operating requirements. Compressor casings should be designed for the maximum possible pressure that can be obtained under any condition of operation, including the surge point.

a. Capacity Control - Capacity may be controlled by the use of inlet guide vanes, suction throttling, blow-off, or speed variation. Consideration should be given to the lubrication of the guide vane mechanism to prevent corrosion.

b. Anti-Surge Control - All axial and centrifugal compressors should be equipped with an automatic anti-surge control system with a suitable bypass or blowoff valve. The response time of the anti-surge system should be consistent with the dynamics of the process system.

c. Check Valve - A check valve should be installed in the discharge line of all dynamic compressors.

d. Sealing Systems for Air and Inert Gas - In general, labyrinth-type seals are satisfactory for all air and inert gas compressors. On high pressure machines, that is, in excess of 200 psi, consideration should be given to using a stepdown-type labyrinth seal where an intermediate pressure is bled back to the process gas interstage of the compressor, thus reducing the final sealing pressure and resultant leakage.

e. Lubrication Systems - A lubrication system consisting of reservoir, cooler, filters, pumps, and auxiliary equipment should be provided. The reservoir bottom should be sloped away from the pump inlet end to allow for settling of dirt and water. Ample air disengaging space should be provided between the maximum oil level and the top of the reservoir. The reservoir top should be sufficiently rigid to allow for the mounting of auxiliary equipment on top of the reservoir without undue deflection or vibration. The oil cooler tube material should be selected using the same criteria as used in selecting the compressor intercooler materials. Dual oil filters are suggested, with a multiport transfer valve. The filters should be equipped with drain and vent valves, and a fill line with orifice should be provided to refill the filter after cleaning. Two full-size oil pumps should be provided using different sources of power. The main oil pump may be driven off the compressor speed-increasing gear, or electrically driven, and the auxiliary pump driven by a-c or d-c power, air, or steam. In any event, the auxiliary pump should be driven from a dependable source of power if for any reason the main line pump power source should fail. The reservoir should be equipped with an oil level gauge, vent connection, and a separate fill connection.

f. Lubricants - A good grade of mineral oil with a viscosity consistent with the manufacturer's recommendations should be used. The oil should contain rust and oxidation inhibitors and a foam depressant. It is suggested that the oil be tested monthly or at a period determined by operating experience to determine any loss of lubricating properties or increase in foreign materials.

g. Monitoring Devices - Depending upon the compressor size and application, the points to be considered for indicators, remote alarm or shutdown devices are:

1. Inlet gas pressure at each casing
2. Final gas discharge pressure
3. High gas inlet temperature
4. High gas discharge temperature
5. Lube oil pressure before and after the filter
6. Lube oil pressure at the most remote point in the system
7. Lube oil temperature to the compressor
8. Low reservoir oil level
9. Bearing temperature
10. Cooling water pressure
11. Cooling water temperature
12. Shaft vibration
13. Shaft axial movement
14. Motor winding temperature
15. Motor current
16. For oxygen machines only, pressure indicators and safety switches on the oxygen seal system

On large compressors, it is suggested that a single four-position lube oil pressure switch, or multiple switches, be provided in the lube oil pressure system. This switch, or switches, should provide an alarm on low pressure, start up the auxiliary oil pump, shut down the compressor, and provide a permissive start signal. It is recommended that the shutdown switch be provided at the most remote point in the lubricant system.

A proximity-type vibration monitor is strongly recommended for all axial or centrifugal compressor installations. The proximity probes should be installed to measure shaft movement and actuate alarm and shutdown systems. The anlaysis of data derived from vibration measuring equipment is frequently difficult and it is advisable to have units diagnosed by one experienced in the field. Theoretically, a machine should not be restarted until the cause of the excessive vibration reading is determined and corrected.

Care should be exercised on location of safety devices so they are not subject to vibration.

3. Positive Displacement Machines

This category includes not only the normal reciprocating type of compressors, but also diaphragm machines and rotary compressors.

a. Reciprocating Compressors - In general, reciprocating compressors of the industrial water-cooled, cross-head type are used in the air separation industry. Reciprocating compressors should have replaceable type main bearings and connecting rod bearings.

Where possible, crosshead shoes should be replaceable. If it is intended to use synthetic lubricants in the compressor cylinders, either initially or at some future date, the compressor crankcase should be painted with a paint, such as epoxy, that is resistant to synthetic lubricants.

The ratio of compression in compressor cyclinders should be limited in order to restrict the resultant gas discharge temperature. In general, for hydrocarbon-lubricated compressors, it is suggested that the discharge temperature be limited to 325 F.

b. Valves - Where compressor valves are interchangeable between the inlet and discharge, it is suggested that the valves be polarized to prevent the insertion of a suction valve in a discharge port. This is particularly important where only two valves per cylinder end are used, and in oxygen compression service.

c. Lubricated Cylinders - A separate forced-feed cylinder lubricator should be provided for lubricated cylinder construction. In cases where use of a synthetic lubricant in the cylinder is contemplated, the cylinder lubricator should be equipped with sight glasses and seals compatible with synthetic lubricants. The lubricator shall be completely separate from the crankcase lubrication system and, where multiservice compressors are used, a lubricator with separate compartments should be provided to allow for different lubricants to be used for each service if it should become necessary.

d. Lubricants - The selection of lubricants for the running-gear or crankcase and cylinder lubricants should not be confused, and almost always different lubricants are used for crankcase and cylinder lubrication. A good grade of mineral oil with a viscosity consistent with the manufacturer's recommendations should be used in the crankcase. The oil should contain rust and oxidation inhibitors and a foam depressant. On small compressors it is advisable to change oil at regular intervals. For large units it is suggested that the oil be tested periodically to determine any loss of lubricating properties or increase in foreign materials, and be changed when necessary.

The compressor manufacturer will normally recommend the specifications for the cylinder lubricant depending upon the expected temperatures, cylinder size, piston speed, and the characteristics of the gas compressed.

If it is desired to use mineral oil for cylinder lubrication, it is much more important to use an oil having the lowest carbon forming characteristics, than to have a high flash point. It should have a fairly high viscosity for good film strength, and should be inhibited to minimize corrosion and rusting.

Synthetic oils of the phosphate rester type are widely used in air compressor service, and are available in several viscosities to meet normal requirements.

The advantages of the synthetics are:

1. They are less combustible and have higher auto-ignition temperature.
2. Deposit formation is soft and easily removed.
3. Maintenance of valves, piping and intercoolers is decreased.
4. If an ignition should occur, there is less fuel in the form of hydrocarbonaceous deposits to add violence to the occurrence.
5. Lower vapor pressure makes oil removal equipment more effective.

Some disadvantages of synthetics are:

1. They are slightly toxic.
2. They are not compatible with plastics and rubber.
3. They attack some paints.
4. Their vapors are harmful to electric wiring and insulation
5. They are more vulnerable to water wash, thereby causing corrosion.
6. There are difficulties in condensate disposal and "breaking" the emulsion of the water-lubricant mixture.

Any mixture of synthetic and petroleum oil for cylinder lubrication is no safer than straight petroleum oil, although the mixture does result in softer deposits.

To use synthetics, the compressor should have been built specifically for their use. If an existing compressor is converted from petroleum to synthetic oil, both the compressor and the lubricant manufacturers should be consulted. Usually the complete interior of cylinders, lubricators, intercoolers and interconnecting piping must be thoroughly cleaned. Any plastic sight glasses on lubricators must be replaced with glass. All rubber and neoprene gaskets must be replaced with Teflon or asbestos types. The compressor manufacturer should supply crankcase and piston rod scraper rings so that the synthetic cylinder lubricant cannot get into the crankcase which will still use petroleum oil. A compressor using synthetic cylinder oil should have the petroleum crankcase oil examined every week to be sure that it is not being so contaminated. A simple test of specific gravity will provide a good indication because the gravities of each are quite different.

The cylinder lubrication rate should be the minimum to wet the entire cylinder wall. Any more is wasteful and results in excessive deposits on valves and in passages. There should be no pools of oil in valve chambers or interconnecting piping. Depending upon the type of oil and the lubricator, one drop from the lubricator per minute per cylinder is generally sufficient for 1000 square feet of cylinder surface swept per minute. The compressor builder will suggest feed rates for each cylinder as a start, but experience on subsequent inspections should be the guide for further adjustments.

Oil removal from reciprocating compressors starts with the separators and traps after each stage intercooler, and at the separator following the final stage aftercooler. Much of the oil vaporized into the air stream will be condensed into a mist in the coolers, form droplets in the separators, and be drained. However, some oil vapor will remain in the air stream.

In high-pressure plants (usually over 600 psig air pressure) where absorptive driers are used for moisture removal, a "pre-filter" vessel may be installed. This usually contains silica gel or activated alumina which serves as a mechanical contact seperator to knock out remaining water and oil droplets which are then drained. The driers then remove any remaining moisture and oil vapors. The absorptive bed will in time lose its effectiveness for moisture removal by becoming oil saturated, at which time the drier beds should be renewed.

In plants using low pressure air, or where driers are not used for water and oil removal, more specialized oil vapor removal equipment is required. This system usually consists of a venturi type coalescer which by velocity change and impingement on baffles in a centrifugal separator reduces oil vapor droplets of oil which can be drained. This is then followed by some type of extended surface filters or absorptive bed for final oil vapor removal. This system is most effective if the air system has been cooled to a temperature of 40 or 45 F.

e. Water Lubricated Cylinders - In the early days of the oxygen industry, soap-water solution, or just plain water was used as the cylinder lubrication of reciprocating oxygen compressors. This type of unit is still being manufactured and is in operation in many plants today. Generally, those using plain water are multistage vertical machines, and horizontal machines require the soap-water solution. The standard soap used is a pure castile. Detergent type soap should never be used.

After every 2000 hours of operation, the entire oxygen system through the compressor should be cleaned out to eliminate buildup of dry soap deposit. At least every 8000 operating hours, the water separators following the final aftercooler and the gas driers should also be cleaned.

It is important that controls are provided to prevent operation of these compressors when lubricating water or soap-water is not feeding the cylinders and cooling water is not flowing.

f. Halogenated Lubricated Cylinders - Halogenated lubricants are available which are chemically inert and safe to use for oxygen compressor systems. These cylinder lubricants are very expensive, so their use is mainly in automatic unattached plants, and generally at lower discharge pressures than normally encountered in plants filling cylinders and tube trailers.

Precautions should be taken since halogenated lubricants have an affinity for moisture and a lower viscosity index than petroleum lubricants. Separators have been used to recover this lubricant from the gas stream and it can be reused with proper reprocessing.

g. Non-Lube Cylinders - It is implied that non-lube compressors refer to compressors having no lubrication in the cylinders, valves, or packing. The lubrication system of the crankcase is identical with other types of reciprocating compressors. Care should be used in the application of non-lube compressors, with special consideration given to the piston speed and differential pressure across the piston rings. There are several materials available for non-lube piston rings. Most prevalent in use is filled-Teflon, which has been used extensively in air, inert gas, and oxygen service. Particular attention should be paid to the finish on the cylinder walls in non-lubricated service, not only at the time of initial installation, but also during major maintenance periods. Compressor valves in non-lubricated service should have Teflon or equivalent wear buttons or guides.

It is suggested that non-lubricated rod packing in oxygen service be water cooled.

h. Distance Pieces - Single-compartment, open distance pieces are acceptable in air or inert-gas-lubricated compressor service. Where synthetic lubricants are used in the cylinder, two directional wiper rings should be used in the frame end packing to prevent the migration of synthetic lubricants into the crankcase. In nonlubricated service, a two-compartment distance piece is recommended. The compartment adjacent to the frame should be extended and a flinger should be attached to the rod in this compartment. In high purity gas service it is suggested that the cylinder end compartment be pressurized to prevent the inward leakage of air into the product.

i. Capacity Control - Capacity control is normally accomplished on reciprocating compressors by clearance pockets, valve lifters, valve unloaders, or bypass from the cooler outlet to the cylinder inlet. Care should be used in the selection of clearance pockets to limit the capacity reduction in one end of a cylinder to not more than 50 percent to prevent recompression of gas and resultant overheating. Valve lifters should be considered whenever it is desired to reduce the capacity of a cylinder by 50 percent for a considerable period of time. This system has the advantage of removing the valve entirely from the gas stream and the gas does not flow through the valve seat passages, such as occurs in valve unloaders.

Variable hydraulic valve unloaders may be used in air or inert gas service. This type of unloader is a proprietary design and has the advantage of unloading the cylinder during a variable portion of the stroke. It is not suggested for use in oxygen service due to the possibility of a rupture in the hydraulic system. The use of any internal capacity control system, as described above, in oxygen service should be critically examined. The possibility of failure in clearance pocket valves and valve unloaders should be weighed carefully against the advantage of power savings.

Start and shutdown bypass or blowdown valves are recommended for all large reciprocating compressors.

j. Safety Valves - A full capacity safety valve should be installed following each stage of compression.

k. Pulsation Bottles - A pulsation bottle should be installed in the inlet and discharge of the compressor and interstage, where necessary to limit piping pulsations.

l. Special Consideration for Nitrogen Service - In operating a lubricated reciprocating nitrogen compressor, there is a possibility of accumulating a quantity of unoxidized carbonaceous material. Explosions have occurred in these systems when the oxygen content of the gas increases significantly above normal. The nitrogen system should be monitored to indicate a significant increase in oxygen concentration. It is also recommended that lubricated reciprocating machines used for long periods in nitrogen or any other inert gas service be inspected and cleaned, if necessary, of wear particles or lubricant deposits before being placed in air service.

In nonlubricated compressors the service life of fill-Teflon piston rings must be watched closely since the nitrogen gas does not provide any lubricity and ring life may be substantially shortened.

m. Monitoring Devices - Depending on the compressor size and application the points to be considered for indicators, remote alarm, or shutdown devices are:

1. Compressor inlet pressure
2. Discharge pressure of each stage
3. Inlet gas temperature to each stage
4. Discharge gas temperature from each cylinder
5. Lubricating oil pressure
6. Lubricating oil temperature
7. Lubricating oil sump level
8. Cylinder lubricator malfunction
9. Cylinder lubricator reservoir level
10. Cooling water pressure
11. Cooling water flow
12. Cooling water temperature from each intercooler
13. Cooling water temperature from cylinder jackets and oil cooler
14. High vibration
15. Motor winding temperature
16. Motor current

It is suggested that that a seismic-type vibration switch be installed on all reciprocating compressors. On large units, at least one switch should be considered for each two compression throws.

Care should be exercised on the location of safety devices and instruments so that they are not subject to vibration.

4. Diaphragm Compressors

Diaphragm-style compressors are normally used where low volumes and high pressures are encountered. The running gear, cooling, and monitoring requirements are similar to the reciprocating compressor requirements. A filter with a fine degree of filtration is recommended on the inlet of all diaphragm-style machines.

Consideration should be given to installing a photoelectric cell type leak detector in the gas line down stream of the compressor to detect leaks or cracks in the diaphragm.

When a diaphragm type machine is used in oxygen service the hydraulic fluid under the diaphragm should be soap-water solution or halogenated fluid which is safe for use in oxygen. This is because diaphragms can develop a fatigue crack and the hydraulic fluid will come in contact with the oxygen gas.

5. Rotary Positive Displacement Compressors

This type of machine is generally used for moderate to low pressure applications in air and inert gas service and can be provided with either labyrinth seals or gas buffered seals. Lobe type units are frequently used in dryer reactivation service and in this instance Teflon impregnated packing is suggested to prevent the migration of oil into the gas stream during reactivation.

6. Oxygen Compressors

Most compressors used by industry for oxygen are either reciprocating or centrifugal. Generally reciprocating compressors are used for small to moderate flowrates where low to moderate pressures are required. For high flowrates and high pressure a centrifugal and reciprocating compressor are often used in series. Centrifugal compressors require at least 500 cfm actual flow at the last stage of compression for reasonable performance and are generally limited to about 500 psig discharge pressure. Applications with less flow or with higher pressures are usually accommodated with reciprocating compressors.

a. Centrifugal Compressors - Centrifugal compressors are used more in recent years due to large volumes of gas to be transferred. High rotating speeds are necessary with centrifugal compressors since the pressure is developed by kinetic energy. Because of the high rotating speeds, accidental rubs between the rotor and case are likely to produce a fire.

The materials used for construction of a centrifugal compressor are generally a compromise between oxygen compatible materials and materials having proper mechanical design properties. The compromise materials must be such that they are compatible with oxygen in the normal mode of operation but may not necessarily be compatible in the event of a malfunction due to internal rubbing during operation. The prime example of this condition is the common use of stainless steel alloys for rotors, and steel or iron alloys for the case. A high velocity rub between the impeller and the case has caused several fires wherein the impeller has been consumed by fire and the case has burned through. Since compatible materials are not available or are prohibitively expensive the compressor is designed to minimize the chances of rubbing.

b. Reciprocating Compressors - Reciprocating compressors have been used for many years in oxygen service, but until recent years they have been used mostly for small, high-pressure units. Prior to the advent of Teflon, and similar materials, for piston rings and piston rod packing, most compressors were operated with a soap-water solution for lubrication or used carbon-graphite sealing materials and wear parts. Also in use has been the labyrinth type piston compressor and the diapgragm type compressor.

Present day reciprocating compressors are mostly Teflon ring construction of labyrinth piston construction with a few diaphragm compressors used for low flow, high-pressure applications.

7. Design Criteria for Dry Oxygen Service (dew point -40 F or below)

a. Compressor - Design criteria are as follows:

1. Materials of construction exposed to the process stream shall be compatible with high pressure oxygen. The use of carbon steel for surfaces exposed to oxygen is prohibited. All parts shall be identified as to material to permit an adequate engineering review.

2. Reciprocating compressors inlet and discharge valves shall not be interchangeable.

3. A suitable distance piece shall be provided to separate oil lubricated portions of the compressor from the oxygen stream with adequate ventilation and slingers provided.

b. System Equipment - Design criteria are as follows:

1. Where the oxygen source is liquid or a possiblity of liquid carryover exists (storage tank flash recovery), the design of the suction piping shall provide a trap to prevent liquid carryover into the compressor.

2. Design engineering standards on piping shall be followed where carbon steel piping is provided on the suction side of the compressor with a stainless steel firebreak provided immediately adjacent to the compressor inlet.

3. An adequately sized connection for a source of dry nitrogen or dry oil-free air (nonlubricated compressor) to the compressor suction shall be provided for startup and run-in of the compressor.

4. Compressor discharge piping upstream of interstage and aftercoolers shall be copper, red brass, or stainless steel suitable for the pressures involved. Piping downstream of the coolers may be carbon steel with a stainless steel firebreak immediately adjacent to the next stage of compression. Maximum allowable velocities for carbon steel piping must be observed.

5. Where compressor bypass lines are provided, the bypass shall originate downstream of the cooler. The bypass may be carbon steel piping. The bypass control valve shall be stainless steel or copper alloy.

6. Flanges shall be provided for removing suction, interstage, and discharge piping for inspection of the compressor system.

7. Intercoolers and aftercoolers shall utilize stainless steel, copper, or copper alloys for the inlet head, tubes, and tube sheets. The discharge head may be carbon steel or cast iron subject to analysis and approved of velocity and impingement conditions.

8. Piping downstream of the aftercooler shall conform to piping design engineering standards.

9. A check valve shall be installed in a section of the discharge piping remotely located from the oxygen compressor to prevent backflow of oxygen in the event of compressor failure.

10. Discharge surge vessels on reciprocating compressors shall be stainless steel or copper alloy construction. Suction surge vessels may be carbon steel where velocity and impingement conditions are not severe. Corrosion resistant coatings, such as Kanigen plating, or equivalent, may be utilized for vessels when velocity or impingement is considered critical.

11. Stainless steel or copper alloy line strainers shall be provided in the suction piping of all compressor system.

12. Deviation from stainless steel or nonferrous materials to corrosion resistant plated carbon steel, Kanigen or aluminized carbon steel, must be reviewed for approval for safety by qualified persons.

c. Instrumentation - The following instrumentation shall be provided in the oxygen compressing system:

1. Emergency Controls

    a. A fail-safe automatic block valve should be installed on the suction side of the compressor to close on compressor shutdown.

The following compressor shutdown devices are required and shall also close the automatic block valve:

- A low-temperature switch on the suction piping of any compressor taking suction from a possible cold source.

- A low-pressure switch on the suction piping of a compressing system.

- A high-temperature switch should be installed on each stage discharge prior to the cooler. The maximum permissible setting on high-temperature switches shall be:

Alarm	325 F
Compressor Shutdown	350 F

  Each location shall re-establish a lower setting when experience with operating temperatures indicates this is possible.

- A vibration switch should be installed on reciprocating piston compressor frames.

- A low oil pressure switch should be installed where applicable.

b. A minimum of two emergency stop buttons shall be provided which will close the automatic block valve and shut down the compressor(s). These shall be located in an area protected from the compressor by a minimum distance of 25 feet or by a masonary partition. A start-stop push button station shall be located adjacent to each compressor. Oxygen compressors on low-pressure plants over 150 T/D shall have one stop button in the control room.

2. Visual Indicators

All visual indicators shall be visible from the operator area, where practicable, and shall include:

- A local dial-type temperature indicator should be installed on the discharge of each compressor stage or centrifugal casing. A local temperature indicator should be installed at the inlet on each compressor stage or centrifugal casing having a 100 horsepower motor or larger.

- A pressure indicator should be installed on each stage discharge.

- Each alarm and shutdown device shall be tied into an annunciator panel with an alarm in the compressor area, and where practicable, a common visual indicator and alarm located in the control room.

3. Safety Valves

Safety valves shall be provided as required and shall be piped to the compressor suction or to an elevated vent outside the building.

d. Location - Compressors and equipment should be located as follows:

1. The oxygen compressor shall be located to minimize exposure to operating personnel and to associated equipment. Special consideration shall be given to isolation of compressors in the following instances:

   - Oxygen compressors on tonnage plants processing a major plant flow
   - Small capacity compressors located adjacent to major equipment (The involvement of additional equipment in a large tonnage plant which could add to the exposure to personnel and equipment must be carefully evaluated.)

2. Isolation of oxygen compressors, where required, may be provided by spacing of equipment, barricades, or a separate room. Where a separate room is provided, the installation shall include fire resistive materials of construction, two means of egress, panic hardware, and a ventilating system. The ventilating system shall have a failure alarm.

The minimum distances listed in Table 5 are intended to prevent crippling damage to surrounding equipment and minimize personnel exposure in case of an oxygen fire within the personnel protective shield. Increased distances may be required to minimize height of personnel shields as balanced against higher cost of longer pipe runs, etc.

8. Design Criteria for Wet Oxygen Service (dew point above -40 F

On compressors processing wet oxygen or water solution lubricated oxygen compressors, all compressor system piping, valves, and associated vessels shall be stainless steel, copper, or copper alloys. The criteria listed for dry oxygen service (dew point less than -40 F) are applicable except where contradictory to the above condition.

9. Coolers and Separators

Intercoolers should be provided after each stage of positive displacement compressors and are frequently used in conjunction with dynamic machines to remove the heat of compression and improve efficiency. Cooler tube material should be selected based on the characteristics of the gas and cooling water. Special consideration should be given to chemical impurities in the atmosphere which may cause acidic conditions in air compressor intercoolers resulting in stress corrosion of the cooler tubes. An adequate supply of clean treated cooling water is essential.

TABLE 5. EQUIPMENT LOCATIONS FOR SAFE OPERATION

Item	Distance from Oxygen Compressor (feet, minimum)
Major Equipment (cold boxes, air compressors, etc.)	20
NOTE: Oil console for any other compressor shall be positioned so its compressor lies between the console and the oxygen compressor.	
Backup Equipment (storage tanks, pumps, vaporizers, electrical gear, etc.)	50
Flammable Equipment (cooling towers, etc.)	50
Buildings (office, maintenance, etc., where people congregate)	50
Natural Passageways (for normal plant operation)	10
NOTE: 1. Except when intentionally going to oxygen compressor. 2. Where necessary, chain fences and signs shall be utilized to reroute personnel.	
Public Thoroughfares or Buildings	50

Moisture separators should be installed following each stage of cooling on wet gas compressors. High efficiency separators are desirable to prevent the carry over and deposit of dirt on suceeding centrigual compressor wheels or the slugging of liquid into reciprocating compressor valves resulting in valve breakage and washing lubricants from the cylinder walls.

10. Compressor Piping

Compressor piping should be adequately braced to prevent excessive vibration. Expansion joints should be installed, particularly on centrifugal machines, to prevent piping stresses from being transmitted to compressor casings. Low point drains should be provided in the gas and water piping, and high point vents are recommended in the water piping.

11. Refrigerant Gas Compressors

Both centrifugal and positive displacement machines have been used in refrigerant service. Generally these machines are much smaller than the air compressors in an air separation plant, but for safe operation they must have many of the same protection and control devices. Particular attention should be given to the design and location of oil separation devices to prevent lubricating oil from entering the evaporator. Positive unloading or an automatic hot-gas bypass should be provided to prevent liquid refrigerant from entering the compressor under low load conditions.

12. Foundations

Compressor foundations should be designed to provide a rigid base for the compressor installation. In designing the foundation, the unbalanced forces of the compressor should be considered, as well as the permissible soil bearing loads and the natural frequency of the soil. It is desirable that the entire compressor package including driver, coolers, pulsation bottles, and interstage piping supports be mounted on a single foundation block. The compressor frame or base plate should be leveled and aligned on the foundation and, after final leveling has been accomplished, the machine should be grouted to the foundation. Laminated shims should be installed between base plates and compressor components to allow for future alignment changes.

13. Air Filters

A filter should be provided on the inlet of all atmospheric air compressors. An oil bath type or rotating oil-washed screen type is recommended for lubricated reciprocating compressors. For dynamic and non-lube reciprocating compressors a dry panel or continuous travelling dry viscous impingement style filter is recommended.

14. Corrosion

Corrosion problems affecting air compressors generally depend on the nature of contaminants in a polluted industrial atmosphere and the quality of available cooling water. In locations where acid fumes and hydrocarbons are prevalent, a water wash system may follow the dust filter. The air intake piping should be galvanized or coated on the inside to preclude rust and scale formation which could seriously damage the compressor.

15. Procedures

Written operating procedures should be obtained for each major compressor unit. A checklist for starting each compressor should be prepared and posted on the compressor gauge board or adjacent to the start switch. The most critical period for most compressors is initial startup or starting after prolonged shutdown. Vibrations and oil temperatures should be critically monitored especially during the first few minutes after starting. A temporary fine mesh screen (conical type, pointing up stream) in the inlet flange is an excellent precaution against pipe scale and debris that may be trapped in the piping.

16. Operating Logs

A logbook should be maintained on each item of equipment and the temperatures, pressures, and capacities should be logged periodically each shift. Changes in values for any given instrument should be immediately called to the attention of the operating supervisor.

17. Preventive Maintenance

A preventive maintenance schedule should be prepared for each compressor. Equipment should be shut down on a periodic basis and all wearing parts should be inspected.

- Check list for Centrifugal Compressors
  1. Vibration readings on all bearings
  2. Bearing clearances
  3. Intercooler cleanliness
  4. Inspection of compressor rotor for dirt
  5. Inspection of compressor rotor for balance
  6. Calibration of all safety devices and gages
  7. Calibration of anti-surge system
  8. Operation of check valve
  9. Hot alignment check
- Checklist for Reciprocating Compressors
  1. Check on temperature of all valves
  2. Compressor frame vibration
  3. Condition of grouting
  4. Oil filter
  5. Lubricator operation
  6. Calibration of all switches and gages
  7. Intercooler cleanliness
  8. Bearing clearances
  9. Crank shaft cheek deflection
  10. Inspection of all valves

E. MOLECULAR SIEVE ABSORBENT AIR SEPARATION PLANT

This is a noncryogenic process that can furnish a 90-percent oxygen stream from an air feed using molecular sieves to achieve the separation. A schematic is given in Figure 44.

1. Compressors

a. Feed Air Compressors - Both rotating (axial and centrifugal) and reciprocating (positive displacement) compressors have been used to supply compressed feed air to molecular sieve adsorbent air separator units. A nonlubricated feed air compressor is essential because contamination of the adsorbent bed

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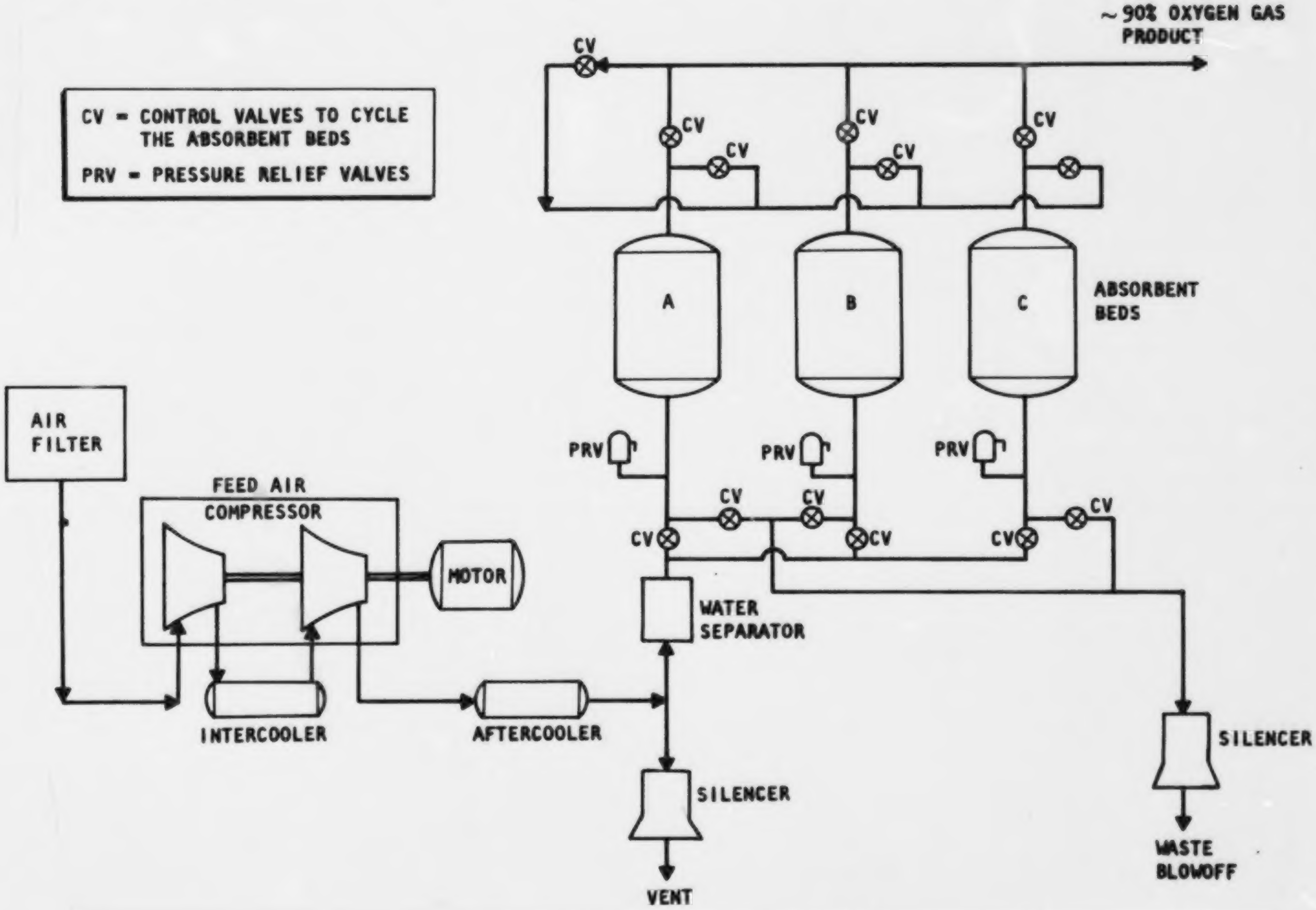
CV = CONTROL VALVES TO CYCLE THE ABSORBENT BEDS
PRV = PRESSURE RELIEF VALVES
~90% OXYGEN GAS PRODUCT
CV
ABSORBENT BEDS
A
B
C
PRV
AIR FILTER
FEED AIR COMPRESSOR
MOTOR
INTERCOOLER
AFTERCOOLER
WATER SEPARATOR
SILENCER
VENT
SILENCER
WASTE BLOWOFF

Figure 44. Molecular Sieve Absorbent Air Separation Plant

with oil vapor presents a safety hazard. For reciprocating compressors, rings can be constructed of filled Teflon.

The pressure levels required for the adsorbent beds feed air ranges around 60 psig, lower than pressure required for cryogenic plant feed air. The compressor discharge temperature should be less than 275 F.

Monitoring devices, including alarms and automatic shutoff should be used. Among the conditions which should be used to signal compressor trouble or shutdown are:

- High oil temperature
- Low oil pressure
- Final gas discharge pressure
- Final gas discharge temperature
- Vibration
- Bearing temperature
- Motor Overload
- Cooling water, low pressure

Other compressor alarm or shutdown indicators which are not associated with possible compressor malfunctions are:

- Low oxygen purity from adsorbent beds (less than 85 percent)
- Low product oxygen pressure
- Low instrument air pressure
- High combustible gas concentration in sewage treatment unit

If a combustible gas alarm condition occurs in an oxygenated sewage treatment process (which normally relies on an air purge from the air compressor) when the air compressor is shut down for any reason, then the sewage treatment process may need to be closed down failing an alternate source of purge air. Care should be employed in locating safety devices so that they are not subject to excessive vibration.

Compressor discharge pressure, and hence the adsorbent bed pressure, should be controlled at the desired level, e.g., a pressure controller compares the process pressure signal with the controller set point signal and adjusts a compressor suction throttle valve accordingly. Pressure relief valves should be installed between the compressor and the adsorbent beds, and check valves should be installed in the discharge line of dynamic compressors.

b. Instrument Air Compressor - Instrument air for operating the valves to the adsorbent beds can be supplied by taking some compressed air from the feed air compressors and using a booster compressor or by using an independent air supply system. Instrument air pressure should be monitored; a low pressure should cause the feed air compressor to shut down. Systems utilizing feed air and a booster compressor may require an auxiliary gas supply (several K-cylinders) for instrument air during start up operations.

c. Coolers and Separators - Intercoolers should be provided after each compressor stage to remove the heat of compression and improve efficiency. Inclusion of a feed air water separator is vital to the operation of the adsorbent beds. Liquid water must not be allowed to contact the molecular sieve. Failure of the automatic water drain from the separator, which causes a high water level, should sound an alarm and eventually shut down the feed air compressor.

d. Piping - Compressor piping should be well supported and equipped with expansion joints to dampen vibrations and prevent the transmission of piping stresses to the compressor.

2. Adsorbent Beds

Packed beds of molecular sieve are used in a cyclical operation to separate oxygen from a compressed feed-air stream. Normally, three or more beds should be used, with the operating cycle staggered, so that while one bed is delivering oxygen to the line the others are in various stages of regeneration so as to provide a more or less continuous air separation operation. The various operating cycles are regulated by compressed air actuated valves. These adsorbent beds should supply oxygen at a purity of 90 percent. No smoking shall be permitted in the vicinity of the absorbent beds.

Containers for adsorbent beds can be constructed of carbon steel and should have top and bottom openings for charging with the molecular sieve and for cleaning. The bed, controls, and piping can be skid mounted for smaller units, or erected in the field.

a. Control Valves - Control valve bodies are constructed of aluminum bronze alloys. O-ring seals can be Viton A, Teflon, and Kel-F. The valve seats should be of glass filled Teflon or a similar inert material.

Positioning of manual control valves and limit-stop positions on automatic valves must be initially adjusted only by the system manufacturer. The adsorbent bed air separation unit should not be started if valves controlling gas flowrates into and out of the beds have been misadjusted or tampered with. Serious damage can be done to the molecular sieves unless these valve adjustments have been properly made.

b. Bed Packing

- Liquid water must not be permitted to contact the absorbent.
- The molecular sieve adsorbent must not be packed until shortly before startup.

- Do not open sealed molecular sieve containers until immediately before loading the bed and prevent exposure to moisture.
- Do not pack the beds during rain or snow fall or when humidity is high.
- Follow manufacturers instructions on molecular sieve loading to obtain a uniform, high packing density bed. Settling and migration of packing must be avoided.
- Top of bed must be level, not cone shaped.
- Fill the void at the top of the bed as specified by the manufacturer.

c. Monitoring Adsorbent Beds - The adsorbent beds are isolated by valves closing at both ends of the beds under the following conditions:

- Reduced oxygen product purity
    - Alarm if O_2 purity <85 percent
    - Shut down if O_2 purity <80 percent
- Air compressor shutdown
- Excessively high air compressor discharge temperature (normally 95 F).
- Bed control circuit power failure
- Excessively low oxygen product pressure
- High combustible gas concentration in sewage treatment unit

3. Operation

When the molecular sieve bed air separation facility is installed, the vendor will make the proper initial adjustments of the control system.

During normal operation, the cycle sequence and the air compressor will load and unload automatically to meet the product oxygen demand of the sewage treatment system.

A log sheet, containing the normal operating range for a number of readings, should be completed at specified times. The log sheet should involve a check of operating variables of the major components, i.e., compressor, cooling tower, instrument air system, oxygen system, liquid oxygen backup unit (more than half full and tank pressure). Deviations from the limits designated on the log sheet should be reported to the plant engineer.

In addition to the normal day-to-day completion of the log sheet, the operator should be aware of and should inspect, on perhaps a weekly basis, the following items.

1. The water level in the feed air line water separator should be visually checked and the automatic drain should be examined. If the water level in the separator is too high or if the water level alarm has sounded, the air separation facility should be shut down and the trap should be inspected and cleaned if necessary.

2. Check the pressure drop across the air filters which service the instrument air system.

3. Check the cooling tower water pump for water leaks and/or excessive bearing noise. Corrective measures should be taken in accordance with the manufacturers maintenance manual.

4. Check the compressor reservoir oil level sight gage. If oil level is low, add in accordance with the compressor instruction manual. Check area around and under compressor skid for oil leaks.

5. Check the feed air compressor suction filter pressure drop. If pressure is 5 inches H_2O or greater, clean (or replace) filter in accordance with manufacturers instructions.

6. The design temperature for the adsorbent beds is 95 F. If the temperature is above this level, the performance will degrade. If this temperature is greater than 95 F and cannot be attributed to atmospheric conditions, the compressor cooling water system should be investigated.

7. Check the oil level in the booster compressor crankcase, add oil in accordance with manufacturers manual as required.

8. Check the feed air compressor oil filter. If the pressure drop is in excess of 25 psi of the normal pressure drop through a clean filter, replace the filter element.

9. Check the air dryer. If the unit is not cycling, refer to the manufacturers manual for instructions.

10. Check the pilot lights on the main panel. Replace the lights as required.

4. Backup Oxygen Supply

Normal system response will sense falling pressure in the oxygen supply line to the oxygenated sewage treatment process and will cause the stored liquid oxygen backup system to feed vaporized liquid oxygen to the process. Consult section IV, H for details on stored liquid oxygen.

5. Safety Checklist for Molecular Sieve Absorbent Air Plants

a. Air Compressor

- Check oil level in compressor machinery

- Check area around compressor for oil leaks
- Check operation of automatic drain in feed air line water separator
- Inspect all filters for excessive ΔP; clean or replace

b. Water Cooling System

- Inspect cooling tower assembly for proper water level in basin and freedom from litter
- Check cooling tower fan, belt tension, lubrication, and sump
- Check cooling tower water pump for leaks and/or excessive bearing noise

c. Instrument Air System

- Check instrument air receiver drain operation. It should be clear of sediment and capable of exhausting water
- Check instrument air filters
- Check instrument air dessicant for blue color
- Check instrument air compressor oil level and oil pressure

d. Stored Liquid Oxygen Backup

- Check liquid oxygen level and tank pressure

e. General

- No smoking should be permitted in molecular sieve absorbent facility
- Combustible material should not be stored in area adjacent to air separation unit
- Use a nonlubricated feed air compressor
- Do not contaminate the adsorbent beds with oil vapor
- Keep all oxygen piping and vessels clean
- Replace worn out or faulty parts likely to contact oxygen with parts specifically recommended for use in an oxygen evironment.
- Molecular siever adsorbent air separation plants will normally have a stored liquid oxygen backup system in case the plant malfunctions. The reader should consult the Oxygen Safety Check List and the Safety Check List for Stored Liquid Oxygen .

F. CRYOGENIC AIR SEPARATION PLANT

A simple schematic of a cryogenic air separation plant is given in Figure 45. Because of continuing development, plant cycles, equipment, and operating conditions will vary. As a result, some of the following statements about various components comprising a cryogenic air separation plant are fairly general; one cannot hope to produce a guide specific enough to replace a manufacturer's operating manual or one that can anticipate future changes in technology.

1. Intake Air and Its Treatment

Ambient air, entering the air supply system, passes through an air suction filter housing designed to filter the incoming air stream through several stages of filter media. Pickup of large, windblown, airborne particles is avoided by an elevated, low velocity inlet.

Trace quantities of contaminants in the process air, particularly hydrocarbons, have a direct relationship to the safe operation of an air separation plant. As the air separation plant normally will be located in industrial areas, some degree of contamination from industrial and/or chemical operations can be expected. Identification of these contaminants and the levels of concentration at which they will be present permit the process and design engineers to include the necessary equipment and process design and operational techniques to ensure a safe plant.

a. Contaminants - The contaminants of greatest concern are those which are combustible with oxygen, and more particularly, those which have certain physical properties similar to oxygen; thus enabling them to penetrate into oxygen-rich portions of the system. The hydrocarbons which are of the greatest concern include ethane, ethylene, acetylene, and C_3 and C_4 hydrocarbons. Ozone and oxides of nitrogen deserve some consideration, because experimentally it has been shown that they may contribute to reactions in liquid oxygen. Other contaminants, not combustible, which may be corrosive to internal and external plant metal surfaces must be considered. Suspended particulate matter in the air must be removed prior to entry into the plant.

Contaminant Sources--Air pollution can come from a number of sources. Vents, stacks, flares, disposal areas, process leaks and exhausts from internal combustion engines are the more frequent serious sources. Chemical and petroleum processes on adjoining properties and other processes within the air separation plant complex must be carefully examined as contributing to the air contamination.

Contaminant Identification -- Contaminants can be identified by chemical analysis of batch samples taken under the most adverse conditions or continuous analysis, depending on the availability of instrumentation, should be satisfactory. If proper analytical equipment is unavailable, the evaluation may be accomplished by studying maps of the surrounding industrial area on which have been charted the locations of various industries and their vents, stacks, flares, etc., along with information on wind directions.

TYPING GUIDE SHEET

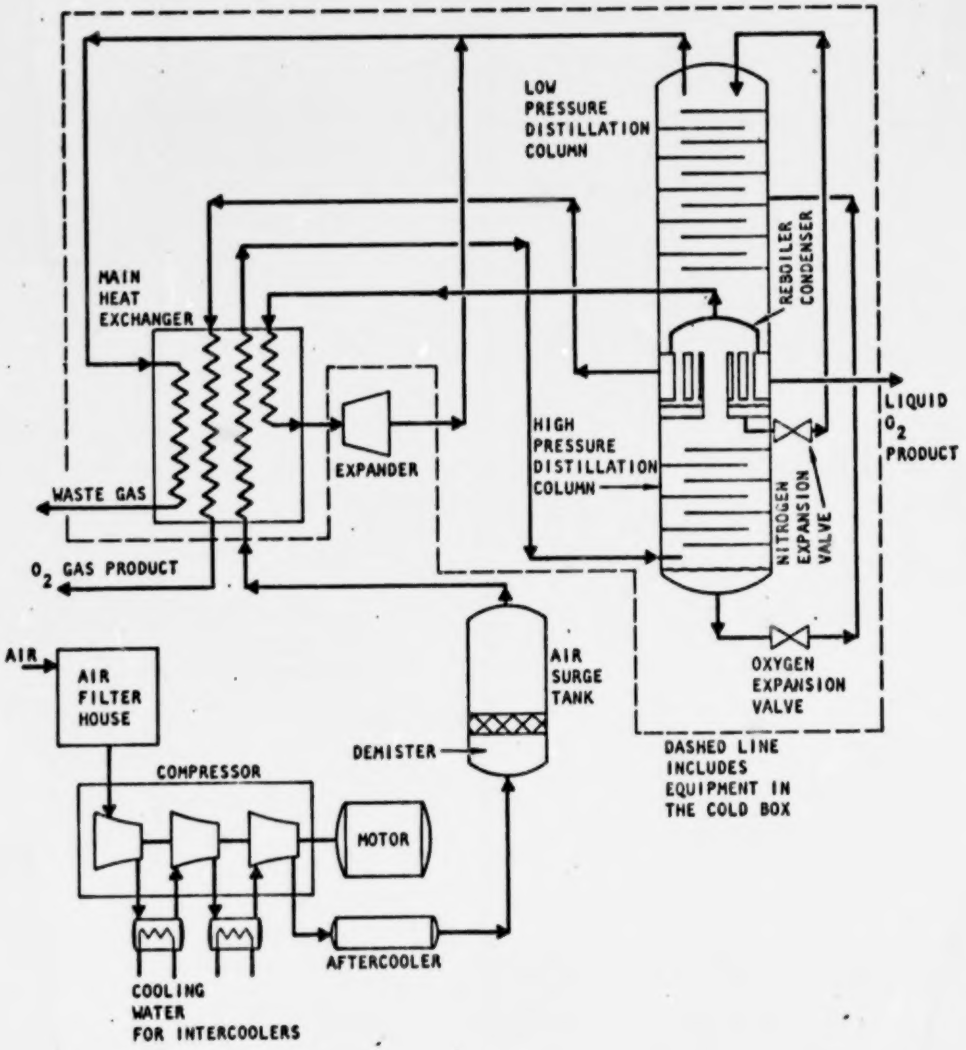
LOW PRESSURE DISTILLATION COLUMN
MAIN HEAT EXCHANGER
REBOILER CONDENSER
LIQUID O2 PRODUCT
EXPANDER
HIGH PRESSURE DISTILLATION COLUMN
NITROGEN EXPANSION VALVE
WASTE GAS
O2 GAS PRODUCT
AIR
AIR FILTER HOUSE
AIR SURGE TANK
DEMISTER
OXYGEN EXPANSION VALVE
DASHED LINE INCLUDES EQUIPMENT IN THE COLD BOX
COMPRESSOR
MOTOR
AFTERCOOLER
COOLING WATER FOR INTERCOOLERS

Figure 45. Cryogenic Oxygen Generator Schematic

b. Location of Air Intake - Distance of the air intake from the source of contaminants for air separation plant safety depends on the following factors.

> Consider the capability to screen and expel impurities effectively to prohibit hazardous levels within the plant. Locate the intake upwind or crosswind if possible, or as far as possible from the contaminant source to take advantage of wind velocity and other weather conditions which can effect contaminant dilution and dispersal. In the extreme case, consider two air intakes, located such that if air at one intake is contaminated, the alternate intake will be either upwind or crosswind from the contaminant sources.

2. Oxygen Pumps

Most pumps used by industry for liquid oxygen have been either reciprocating or centrifugal. Generally, reciprocating pumps are used for small to moderate flowrates and for higher pressures. Centrifugal pumps are used for most all flowrates where low to moderate pressures are required.

Oxygen pumps, both reciprocating and centrifugal, are a specialty item and are available from a limited number of suppliers. The special design features, cleanliness requirements, and relatively small scales volume makes them unprofitable for most pump suppliers.

Materials of construction are similar for both types of pumps and fall into the category of acceptable low temperature materials, namely nickel alloys, copper alloys and aluminum. Generally the nickel alloys are used where high strength is required, copper alloys where rubbing contact is expected and aluminum where light weight is required. The copper alloy generally used is bronze and is the most compatible with oxygen of the low-temperature metals. Nickel alloys are generally the 300 series stainless steel or monel.

Oxygen pumps are generally a simple device with a few controls or instruments. Most pumps have only a suction and discharge pressure gage to monitor their performance. Oxygen pump usage is mostly for transfer operations where the liquid oxygen is transferred from one storage vessel to another and often from a pressure vessel to a higher pressure vessel or pipe line. This transfer duty is mostly on intermittent operations.

Malfunctions and failures of oxygen pumps are probably due more to the intermittent mode of operation than for any other reason. Starting and stopping of any mechanical device is generally considered detrimental to its long-term performance, but with oxygen pumps this condition is greatly exaggerated.

3. Expanders

To balance the various refrigeration losses in the air separation process, heat must be removed from the system. In expanders, work is extracted from high pressure process gas streams during expansion and the gas streams are cooled.

The areas of concern peculiar to operation of expanders falls into the following general categories:

1. Loss of Loading
2. Oil Contamination
3. Excessively low discharge temperature
4. Solids in gas stream
5. Loss of lubrication
6. Abnormal bearing temperature
7. Vibration detection

Maintenance schedules can be arranged on an operating hours basis or calendar basis as most suitable for the specific equipment.

a. Loss of Loading - Reciprocating expansion engines are usually either directly connected to compressors or loaded by electric generators. Expansion turbines are ordinarily loaded by generators, blowers, or oil pumps. If for any reason the loading device fails to continue to apply load to the expander shaft, work created by gas expanding through the expander will cause the expander to increase its speed to a point where mechanical damage may occur.

Expanders are equipped with devices to sense the loss of load as soon as it occurs and shut the machine down before damage can result. Most expanders are also equipped with overspeed switches which will function if the load loss sensing device fails or if loss of load results from an improbable cause.

Both the load loss sensing device and the overspeed switch are designed to stop the motive gas flow either by closing the expander inlet valve or by driving the inlet nozzle or cam to the no-flow position. The system should be designed to ensure that the unloading devices do not unload until the motive gas flow has been stopped. Regular checks, at least annually, should be made to ensure that these devices are operational.

b. Oil Contamination - Reciprocating expansion engines and expansion turbines are discussed below:

Reciprocating Expansion Engines: There are two classes or reciprocating expansion engines, nonlubricated and lubricated.

Nonlubricated machines are designed with extra length open distance pieces between the crankcase and the cylinders. This open section reduces the probability of oil carryover from the crankcase to the cylinders by, (1) providing a place for oil leakage past the crankcase packing to drain, (2) eliminating the necessity of running the same section of piston rod in the crankcase and cylinder, and (3) providing an atmosphere less contaminated with oil adjacent to the cylinder packing.

Cylinder contamination, in nonlubricated machines, can only occur if oil passes from the crankcase, through the crankcase packing, along the piston rod past the cylinder packing into the cylinder. The most effective way to prevent this from occurring is by frequent observation of conditions existing in the open distance piece.

Although oil lubricated expansion engines are designed with oil clean up systems, excessive oil can cause overloading of the clean up system and ultimate contamination of the plant.

Oil feed rate to the cylinder bore should be kept to a minimum compatible with good ring life and cylinder condition. The amount of oil passing through the cylinder of a lubricated expansion engine is not limited to that introduced through cylinder lubricator. Crankcase oil, sometimes in quantities far in excess of this lubricator flow, can be introduced at the crank end of the cylinder. This condition is usually caused by some malfunction of the piston rod oil barriers.

In lubricated expansion engines, close attention must be paid to the oil removal equipment. Oil removal equipment is usually of the packed bed type or the mechanical filter type. The oil removal equipment is operated either for a fixed time period or until a given pressure drop across the system occurs. At this time, the system is removed from service and usually regenerated using a flow of hot gas (preferably inert). It is essential that the volume of regeneration flow and its ultimate effluent temperature is maintained at or above the level specified by the manufacturer.

Some mechanical filtration systems are regenerated by removing the filter media from the filter and washing it in a solvent. The washed media is dried and reinstalled in the filter. Care must be taken to ensure complete washing and drying and to ensure that the media is properly reinstalled to prevent filter bypassing.

The piping immediately down stream from either a packed bed or a mechanical filter should be inspected frequently during initial periods of operation to ascertain that filter bypassing or breakthrough are not occurring.

Packed beds should be replaced as frequently as recommended by the manufacturer unless sufficient operating history exists to allow extending the bed life.

Expansion Turbines: Expansion turbines are designed to prevent oil contamination of the gas stream being expanded. Many turbines employ bearings separated from the gas stream by a triple labyrinth seal. Improper relative fluid pressures in the cavities of the seal can cause oil migration along the shaft into the process gas. If at any time the seal gas pressure drops below normal values, or seal gas consumption becomes excessive, or oil is present in the seal gas vent, the expansion turbine should be shut down, inspected for possible oil contamination, and repaired.

c. Excessively Low Discharge Temperatures - Operators of expanders are usually interested in obtaining maximum refrigeration effect from the machine. Frequently it becomes desirable to operate with as low a discharge temperature as can be practically obtained. The operation of expanders below the dew point of the gas being expanded results in the production of liquid in the expander.

The presence of liquid in a reciprocating expansion engine cylinder will cause major damage and cannot be tolerated. In expansion turbines the presence of liquid droplets can cause wheel erosion and result in rotor unbalance and loss of efficiency.

To prevent the formation of liquid in expanders, it is recommended that the discharge temperature of the expander be held from 5 to 15 F above the dew point of the gas being expanded (depending on the accuracy of the temperature sensing device). Devices used to monitor the expander discharge temperature should be checked regularly in an atmospheric bath of the motive fluid at least once annually.

d. Solids in Gas Stream - Particles in the gas stream, such as pipe scale or desiccant fines, can accelerate ring and liner wear in reciprocating expansion engines, or nozzles, and impeller wear in the turbine expanders. The use of inlet filters is recommended (particularly for nonlubricated reciprocating and centrifugal machines): These filters are ordinarily made of sintered metal, pressed fiber, or finely woven screen. The pressure drop across inlet filters should be monitored to determine when cleaning or replacement is necessary and to ensure that excessive pressure drop, which could cause rupture, does not occur.

e. Lubrication Loss

Reciprocating expansion engine bearings are splash lubricated from the crankcase and force lubricated by pumps, either directly driven from the crankshaft or remotely driven. Loss of lubrication will result in extensive damage.

Pressure switches, designed to shut down the machine in the event of low oil pressure, are normally incorporated in the control system of a reciprocating expansion engine. Machines equipped with both a direct driven and a remote driven pump usually have control systems with two-stage pressure switches. When the pressure drops to the point where the first-stage switch activates, the auxiliary remote pump is automatically started. If the pressure continues to drop, the expansion engine will be shut down when the second-stage switch setting is reached. The pressure switches should be regularly checked.

Centrifugal expanders are lubricated by either direct connected loading oil pumps or remote pumps. Upon experiencing a loss of bearing lubrication, bearing failure will occur in a very short period of time because of the high rotating speed of the machine.

Where direct connected pumps are used for lubrication, an auxiliary pump or coastdown reservoir is necessary. The auxiliary pump may be used in conjunction with a two-stage pressure switch, the first-stage starting the auxiliary pump and the second-stage shutting down the machine. Where coastdown reservoirs are used they should be activated, at the same time the machine is shut down, by a single-stage pressure switch.

f. Abnormal Bearing Temperature - Abnormally low or high bearing temperatures may be experienced in the operation of expanders.

Abnormally high bearing temperatures will be encountered if oil flows to a bearing are restricted, abnormal loading is applied to a bearing, or foreign matter is introduced. Abnormally low bearing temperatures are most peculiar to centrifugal expanders and are encountered in the event of heavy seal leakage or if warming oil flows are restricted.

Most centrifugal expanders and some reciprocating machines have temperature measuring devices usually in the oil stream, but sometimes in the bearing journal. These devices may indicate temperature only or they may have alarm and shutdown contacts incorporated. In the case of indicating devices, operating personnel should watch for significant deviations from normal operating temperatures and investigate their causes.

g. Vibration Detection - The advent of high speed centrifugal machinery, such as centrifugal expansion turbines, has stimulated the development of sophisticated vibration detecting and measuring equipment. Most recent expansion turbines are equipped with vibration measuring equipment of the seismic or proximity probe design. This equipment is considered to be desirable because significant damage can occur to a piece of high speed rotating machinery if excessive vibration is encountered.

4. Cold Box

a. Structural Considerations - The following items must be considered in cold box design.

- Foundations - Foundations should be monolithic, structurally sound, consistent with loadings, vibration, specific area and soil conditions and consistent with local seismic conditions (earthquakes, ground water, etc.)

  A concrete apron should extend several feet out from the base line of cold boxes containing liquid oxygen. The liquid oxygen vaporizers shall be centrally located on an apron extending a minimum of 10 feet from the base of the cold box having a minimum width of 10 feet. A bed of clean gravel, or crushed stone shall extend from the concrete apron to maintain a minimum distance of 20 feet between asphalt roadways and cold boxes.

  Provisions for initial or future heating of foundations (forced or ambient heating) should be included in the initial design to prevent a heat leak through the foundation which will lower the temperature to a point where the earth beneath the foundation will freeze and possibly cause a frost heave of the foundation, or will lower the temperatures to a point which will materially affect the structural strength of the foundation. Thermocouples installed in foundations may be helpful to detect abnormal conditions.

- Overpressure - Overpressure protection devices should be provided on the cold box. The number and kind of devices and set pressure should be based on the configuration of the box, the pressure rating of the box, the purge gas pressure, and also whether mineral wool or perlite is used. These devices should be located to minimize personnel and equipment hazards in case of blowout.

- Insulation and Equipment Support - The insulation used should be oxygen compatible such as perlite or mineral wool. Oil is used as a dust control medium in the manufacture of mineral wool insulation, but it should not exceed 0.15 percent by weight.

- Supports - Wood and other combustible materials should not be used inside cold boxes. Metal structural members or asbestos base material such as Transite shall be used for supporting and bracing of piping and equipment.

b. Process Equipment Separation - The following pieces of equipment should be isolated from the cold box:

- All lubricated machinery shall be installed in a separate insulated box due to potential hazard of lubricating oil or oil mist leaks associated with these units.

- Expanders, centrifugal and reciprocating, shall be a minimum distance of 24 inches from the cold box.

- The drive of the reciprocating oxygen pumps must be located external to the cold box.

- Air-freon heatexchangers on larger plants shall be installed external to the cold box either in their own jacketed enclosure or standing separate with molded insulation. Freon contains oil, picked up in the refrigeration compressor, which would be dangerous in the event of a circuit leak.

c. Oxygen Enrichment of Inert Gas Streams - Analytical alarms and shutdown devices should be provided on recycle nitrogen or other streams which may become oxygen enriched by leaks or plant upsets.

d. Mechanical Filters - Inlet and outlet filters or screens should be provided, to retain the adsorbent in the vessels. Filters should be considered on liquid product streams, between the cold box and storage. Filters for solid CO_2 should be installed where process requires them. Strainers or filters should be provided at pump or expander suction.

e. Hydrocarbon Adsorbers - Adsorbers are provided to remove hydrocarbons which enter the plant in the incoming air stream. To protect contaminants from breaking through prematurely, these adsorbers should be operated on a conservative time basis. They should be both monitored and regenerated more frequently under adverse contamination conditions and preferably regenerated using dry, oil-free nitrogen gas.

The actual point or points of hydrocarbon removal depend on the process design. Some examples are as follows:

1. Rich liquid adsorbers on liquid stream out of the high pressure column sump
2. Cold gas gel trap on air feed to high pressure column
3. Discharge of liquid oxygen pumps
4. Air stream feeding low pressure column
5. Low pressure column sump

An adsorbent material generally used is silica gel. Care should be taken to ensure proper regenerating conditions for complete desorption and at the same time avoid damage to the adsorption properties of the material.

f. Columns, Condensers, Reboilers, etc. - To eliminate hydrocarbon buildup in the remaining oxygen-rich liquid, no liquid-containing vessel should be so located as to be dead-ended.

Contaminant sources and removal points are listed in Table 6.

- Liquid Levels - In a high pressure column, a sufficient level is required to provide seal to ensure liquid to adsorbers. Level during normal operation or shutdown should be such that liquid cannot drain back through the gas feed line, or cause a blind level, and possible hydrocarbon buildup during prolonged shutdowns.

  In a low pressure column, sufficient level is required to dilute contaminants, to keep reboiler surfaces covered, or flushed out to prevent contaminants from concentrating to a dangerous level in the liquid oxygen. Also, sufficient level is required to provide head to pumps.

- Monitoring Contaminants -- Liquid in the low pressure column sump should be check for the following:

  1. Acetylene by use of Ilosvay test or equipment
  2. Total hydrocarbons by use of flame ionization or combustion/infrared
  3. Depending on specific plant conditions, specific hydrocarbons by use of gas chromatograph

  The frequency of testing depends on plant cycles, location of the plant, weather conditions, or any other abnormal conditions which may affect the results. It is recommended that acetylene be checked at least once a day, total hydrocarbons and specific hydrocarbons periodically. Any divergences from normal for the particular plant should be a signal to increase the test frequency and investigate cause of the damage.

  Monitoring of the high pressure column sump or reboiler for CO_2 level can also be a valuable operating or shutdown guide. In plants that employ gel

TABLE 6. CONTAMINANT SOURCES AND REMOVAL POINTS
(Generalized to cover most process cycles)

Location	Contaminants Admitted	Contaminants Removed
Inlet Air	Hydrogen Carbon Dioxide Carbon Monoxide Hydrocarbon Vapors Nitrogen Oxides Waste Fumes and Gases Dust and Other Particulate Matter Water Vapor	
Air Filter	Oil Vapor (only with oil type filter)	Dust and other particulate matter
Compressor (when cylinders are lubricated)	Cylinder Lubricant (as particles and as vapor)	
Intercoolers and Aftercooler		Oil (particulate: if oil is present) Water Water-soluble compounds
Caustic Scrubber		Carbon Dioxide Acidic Compounds
Air Drier		Water Heavier hydrocarbons, including residual compressor oil.

TABLE 6. CONTAMINANT SOURCES AND REMOVAL POINTS (Continued)
(Generalized to cover most process cycles)

Location	Contaminants Admitted	Contaminants Removed
Molecular Sieves		Same as air driers plus CO_2 plus acetylene
Main Heat Exchanger		Bulk of compounds that boil above 90 F and freeze above -270 F will condense and remain until defrost
Reversing Heat Exchanger or Regenerator		Most of the normal contaminants (except acetylene) which would usually be removed in the caustic scrubber, molecular sieves, air drier, and main heat exchanger are removed here.
Expander (when lubricated)	Oil and oil vapor	
High Pressure Columns		Hydrogen and the carbon monoxide will leave with the overhead nitrogen. Other contaminants will leave in the rich liquid.

TABLE 6. CONTAMINANT SOURCES AND REMOVAL POINTS (Continued)
(Generalized to cover most process cycles)

Location	Contaminants Admitted	Contaminants Removed
Hydrocarbon Adsorbers (gas or liquid)		CO_2 removal - very good on gas adsorbers Acetylene removal - very good C_3+ removal - intermediate to very good Ethane removal - intermediate to poor Ethylene removal - Intermediate Nitrogen Oxides removal - very good
Low Pressure Column and Reboiler	Methane can reach the reboiler essentially unaffected by scrubbing, drying, freeze-out or adsorption.	Trace quantities of other contaminants may remain, but the original quantities will have been reduced. The remainder of hydrogen and carbon monoxide will leave with the overhead nitrogen. All other contaminants will be in the liquid oxygen pool.

TABLE 6. CONTAMINANT SOURCES AND REMOVAL POINTS (Concluded)
(Generalized to cover most process cycles)

Location	Contaminants Admitted	Contaminants Removed
Auxiliary Vaporizer		The auxiliary vaporizer is sometimes incorporated in an air separation plant to reduce the hydrocarbon concentration in the reboiler. A portion of the methane and small amounts of ethane and ethylene will leave with the oxygen gas. The balance of these components and all other contaminants will be in the liquid oxygen pool, from where they will be removed by purging or draining.

traps for cleanup of the air to the high pressure column, any level of CO2 in the high pressure column sump other than from a temporary upset or bypassing of the gel trap can be an indicator of gel trap breakthrough. If left uncorrected, this would be followed by the breakthrough of acetylene. A drastic increase in stream temperature can also cause sudden desorption of the contaminants.

For some plants, a level of CO_2 beyond its solubility limit is an indication of potential trouble. Solid CO_2 could plate out in the reboiler and plug passages. Dry boiling could then result in localized and dangerous levels of hydrocarbon concentrations, beyond the safe limit.

- Shutdown Guides - In general, shutdown guides are based on the solubility of the specific hydrocarbons in liquid oxygen and the established safety factor. Safety factors may be influenced by process cycle, type of hydrocarbon contamination, location of plant, weather conditions, etc. Concentrations above the norm for a particular plant, regardless of the safety factor used, are a sign of potential trouble.

  Typical, but not mandatory, shutdown limits are as follows:

  - Acetylene

    0.5 ppm maximum or any abnormal concentration

  - Total Hydrocarbons

    150 ppm (methane equivalent) or any abnormal concentrations, depending on the type of contamination

  - Specific Hydrocarbons

    25 percent of the solubility limit, provided the limits set under above item are not exceeced.

- Solvent Wash -- Plants that may be contaminated by oil and/or hydrocarbons should be solvent washed. Need or frequency of wash depends on the efficiency of oil removal equipment and how far into the plant the contamination goes.

- Safe Holding Time for Liquid Oxygen -- The liquid should be monitored for acetylene and total hydrocarbons. The liquid should be dumped and externally vaporized when acetylene and/or total hydrocarbon concentrations become abnormal. If liquid is not monitored for acetylene and total hydrocarbons, it should be dumped when 50 percent of the liquid has vaporized. Enough liquid should be available to prevent abnormal hydrocarbon concentration during startup.

- Safe Disposal of Liquid Oyxgen -- Liquid oxygen should be dumped and vaporized in a vaporizer external to the cold box utilizing an external heat source.

g. Cold Box and Duct Purging - To exclude moisture and air, cold boxes and ducts should be purged with dry nitrogen. This will prevent the liquefaction of air and will maintain the properties of the insulation. Also, the dry nitrogen will keep the oxygen content to a minimum. Any change of oxygen concentration is an indication of potential trouble. Periodic monitoring may be desirable. Where flammable gases are not contained in process piping inside the cold box the following rules should apply. If an adequate source of nitrogen is available at suitable pressure, it is not necessary to supply a blower specifically for purging. Adequate pressure should be construed as a minimum of 5 psig, or, if the supply is large, for example, from the low-pressure column, a minimum of 2 psig at the outlet into the box should be sufficient. The purge gas purity shall be a minimum of 90 percent nitrogen, and the gas must be dry and oil free.

The purge gas flowrate shall be a minimum of 2 scfm per 1000 cu ft of box volume. Exclude equipment in calculating box volume. As an aid to quick estimating where box volumes may not be known, this purge flowrate is approximately 4 scfm per 1000 scfm air flow to the plant.

Most oxygen leaks tend to concentrate near ground level inside the cold box. About 80 percent of the purge outlets inside the jacket should be distributed evenly as near the base of the cold box as possible; the remaining 20 percent at higher elevations. Purge outlets should be provided near floor ground level close to all oxygen pumps. Purge lines should be sized to handle double the specified flow and should not be pinched at the end. If perlite is used as the box insulation, it will be necessary to add filters at each purge outlet.

Couplings with plugs shall be provided on the cold boxes, (where openings such as removable panel bolt holes, and valve boots are not available), to permit the use of probes to detect oxygen leakage.

Location of the couplings shall be near floor level and at higher elevations that are susceptible to oxygen leaks, such as flanges on adsorbers, flanges on pump filters (on pump bores) etc.

h. Process Leaks - Major liquid leaks and cold gas leaks should be repaired immediately because of possible foundation heaving, perlite erosion of process equipment, overpressurizing of cold box, cracking of carbon steel structural members, and paneling.

First indications of major leaks are frost spots and changes in cold box casing gas purity and pressure.

- General

  1. Procedures for dealing with cold box leaks are necessary in a good maintenance program. Despite continuous nitrogen purging of the cold box, a small liquid oxygen leak can raise the concentration of oxygen to limits that are unsafe for operation and maintenance.

2. Cold box atmospheres shall be monitored weekly for oxygen content to ensure that nitrogen purge is adequate and that no oxygen leakage exists. Monitoring shall be done at several points on each cold box, especially around oxygen pumps, hydrocarbon adsorbers, and guard adsorbers. The appearance of frost spots or vapors may also prompt immediate checks.

   Note: From a safety standpoint, the main concern is with oxygen concentrations higher than 21 percent. These will require action, but any radical deviation from plant norms shall be investigated. For example, if the jacket oxygen concentration of a plant has been running consistently at 15 percent and increases suddenly to 20 percent, a leak check may be worthwhile for process reasons, even through the safety level of 21 percent has not been exceeded.

   Nitrogen leaks shall not be neglected. Locating them may be important for the following reasons: (1) process considerations, (2) because of the possibility of an asphyxiating atmosphere developing, and (3) because pressure ruptures could occur due to embrittlement of normally warm carbon steel piping or vessels.

The procedures in the following paragraphs deal chiefly with oxygen leakage, but portions also apply to nitrogen.

- Action Criteria and Limitations

1. Indications of cold box atmospheres over 21 percent oxygen will require an immediate increase of nitrogen purge. Check all susceptible areas to ensure the oxygen content is 21 percent or lower. Increasing the purge to reduce the oxygen concentration will be limited by:

   a. Availability of sufficient nitrogen to reduce the oxygen concentration to 21 percent or lower.

   b. Large frost spots resulting from the purge. These frost spots may be due to a leak large enough to prevent purge nitrogen heat from warming areas sufficiently or because it is channeling through the box and all nitrogen discharges on a limited area.

2. If increased purge cannot reduce the oxygen content to 21 percent or lower, of if you reach the above mentioned purge limitations and have large frost spots, immediate action shall be taken to locate and repair the leak. If, after finding the leak, it is

necessary to shut the plant down for repairs, the Plant Manager shall be advised of the facts and he shall determine further action.

- Finding Leaks

The following hints are intended to be helpful as a guide to finding leaks. An attempt has been made to list a normal sequence for the average situation, but differing circumstances make it impossible to prescribe a definite course of action. Individual plant peculiarities, the magnitude of the leak, and the nature of surrounding equipment dictate the sequence to follow.

1. Attempt to locate the leak while the plant is operating, if the proper consideration is given to the usual hazards associated with cryogenic liquids, i.e., liquid burns to personnel, increased flammability of materials caused by high oxygen concentrations, and asphyxiation caused by low oxygen concentrations.

2. If possible, increase the nitrogen purge to reduce the oxygen content to 21 percent (or as low as possible) until the leak is located. A clean length of pipe or hose temporarily tied into the reactivation blower can be used. Valve seal boots or removal panels can be used as inlets to the box during supplementary purge. Remeber that to increase the purge flow is at best only a temporary measure, particularly for bad leaks. Supplementary purging may decrease the concentration at the point of leakage.

3. Use an atmospheric oxygen analyzer to locate the area of highest concentration. The highest purity obtained will be a clue to the location of the leak. If the highest purity obtainable is 30 to 35 percent oxygen, the leak will probably be in the crude oxygen circuit. If it is 75 percent or higher, the leak may be in the lower section of the low-pressure column or the condenser. The probe size will affect the concentration reading. It should be as close to the outside diameter of the analyzer sampling tube as practical. Atmospheric influx will also affect the reading, therefore, the distance between the actual and the jacket penetration and the size of the jacket opening are factors that will influence the reading and will need to be considered. Pure nitrogen outlets will also influence the reading. The purge valve may be turned off to take the probe tests, but should be opened again as soon after testing as possible.

4. Check with personnel who may be more familiar with particular plants and their possible weaknesses.

5. Check prints for the areas most likely to cause problems. Flanges, expansion bellows, valve bonnets, orifice unions, etc. would be more likely to leak than welded, soldered, or even threaded joints.

6. After checking the results of the atmospheric analysis, reviewing prints, obtaining a work permit, etc., remove the panel or cut into the box at the suspected area. On welded jackets, a chipping chisel or sabre saw should be used, and a nitrogen purge should be applied at the immediate area. Prints should also have been reviewed to prevent damage to lines and vessels within the box that are close to the jacket. Discontinue cutting periodically and probe ahead through the cut portion to avoid damage to items which may not appear on prints. Cutting torches should not be used for this work. Besides being hazardous, they will not do the neat job necessary for eventual replacement of the panels.

7. When digging into the insulation, chemical goggles or a face shield, long sleeved shirt, clothing free of grease and oil, and asbestos gloves must be used. Personnel will then have maximum protection from a spray of liquid or cold gas.

8. During removal of the rock wool, liquid may be found and followed to its source. However, the liquid may often disappear with exposure to the atmosphere. In such cases, or if it is a gas leak, it may be possible to see or feel the direction from which most of the flow is coming and work in that direction. It should also be remembered that frost spots or liquid at the bottom of a jacket can often be caused by liquid dripping from leaks at higher elevations. Here again, the analyzer can be used to check the concentration to trace the leak back to its source.

9. Where deep penetration of large boxes is necessary, investigation will be limited by the density of the vapors. The atmosphere must contain between 18 and 25 percent oxygen. Lifelines, fresh air blowers, self-contained breathing apparatus, and sufficient standby personnel outside the jacket shall be used as necessary. Storing of rock wool should be provided where required. Constant analysis of the atmosphere in all corners of the cavity is absolutely necessary. When vapors are excessive, it may be necessary to shut down the plant, dig into the box in the direction of the suspected leak, and inspect all joints for leakage. If no obvious leakage is discovered through inspection, the plant may need to be restarted and checked under pressure as long as repair personnel can remain inside. Repeat this digging, inspection, and startup as often as necessary.

10. As a last resort, it may be necessary to defrost the plant and pressure test the various circuits, checking the pressure drop. This is difficult because of possible leakage through valves and because heat transfer to cold insulation will influence pressure drop. If the leak can be isolated to a main circuit, it may be possible to pinpoint it by valving off smaller sections of that same circuit and noting changes in pressure drop rates. As a final check, valves may need to be removed and blank flanges, plugs, etc., installed to ensure an airtight system.

- Repairing Leaks

  If the leak or leaks are located and can be repaired without shutting down the plant, first provide a temporary increase in the purge in the area of the leak with a clean pipe or hose from the reactivation blower discharge or other available source. Ensure that the general working area is clean, and free of oil contamination or any flammable material. Either remove a convenient bolted panel or, if necessary, use a sabre saw to cut a panel opening near the leak. Never use a torch to cut a panel during operation. Remove enough rock wool to expose the leaking flange or valve bonnet. Repair the leak if possible, replace rock wool, being sure it is free of oil contamination (use fresh rock wool if possible), and bolt the panel in place.

i. Potential Cold Box Hazards - When it is necessary to enter a cold box to carry out repairs or modifications, there are the hazards of an oxygen enriched or deficient atmosphere either within the cold box or within the piping or vessels to be worked on, plus the safety considerations associated with the pressures, low temperatures and cold box insulation. Therefore, a prerequisite to any such work with the cold box should be complete draining of all liquid, defrosting and depressurizing. When on occasion it is necessary to enter the cold box without complete warming, careful and complete consideration must be given to the hazards of the cryogenic environment such as limited visibility, cryogenic burns, and a possible unsuitable atmosphere. Under such conditions a supervisory controlled safety work permit is mandatory. In addition, it is perferable to remove all powdered insulation prior to any major work within the casing, as there is no way of knowing if any liquid oxygen or nitrogen is entrained in the insulation at the bottom. With complete insulation removal, washing down of the interior would also preclude possible avalanching and dusting problems associated with partial removal of powdered insulation. Adequate scaffolding and lighting should be provided within the cold box.

j. Entry of Work in Potential Oxygen Enriched or Deficient Atmospheres - Serious injuries or fatalities can occur from having personnel enter an oxygen enriched or deficient atmosphere and therefore, care and precaution must be taken before entering the cold box. Tests of the cold box atmosphere should be taken, and unprotected personnel should be prohibited from entering an atmosphere that does not fall within the range of 20.9 ±1 percent oxygen. For entry into an area which could be enriched or deficient in oxygen, the following general rules should be followed:

1. Check that an unsafe atmosphere cannot be introduced by the operation of any valves, and if the possibility exists, valves should be closed, locked out, and tagged. Where possible, blanks must be inserted in lines which could accidentally cause an enrichment or deficiency in the work area. Line monitoring should be instituted.

2. The area should be purged and tests should be made to ensure that the atmosphere is 20.9 ±1 percent oxygen before allowing personnel entry into the area.

3. A fresh air blower should be used to supply fresh air to any confimed area while it is occupied.

4. Periodic tests of the atmosphere should be taken.

5. A safety harness and lifeline with the lifeline held by another employee outside the work area should be employed.

6. Adequate fire extinguishers should be on hand as well as an audible signalling method.

7. Should exceptional circumstances prevent the achieving of an equivalent air atmosphere, entry could be made with the use of self-contained air packs or equivalent. A lifeline held by an employee outside the area, and an additional employee available to go for further help and specific instructions as to the entry of a second employee into the area, are all conditions that must be adhered to under these circumstances.

5. Shutdown

a. General - In shutting down of an air separation plant, either deliberately, by reason of power failures, or because of equipment malfunction monitors, there is generally a built-in, fail-safe system of shutdown events. Numerous events happen automatically; valves close, vent valves open, equipment is shut down, and generally the plant is in a safe standby condition. If this is not the case, a listing of priority actions such as product disposal and equipment venting should be set up and the operators should be trained to perform the functions required with each individual type of plant.

b. Cold Box Shutdown Considerations - Depending on the type of plant, the reason for the shutdown and the expected length of the shutdown, other safety procedures should be followed. When the shutdown is for periodic defrosting it is normal to combine this operation with maintenance repair and necessary modifications. When the shutdown is not for defrosting, and again depending on the type of plant, there may be problems with gel trap impurity migration and hazardous impurity concentrations in the liquid, both of which are proportional to the length of downtime. In the case of possible gel trap impurity migration, a restarting procedure which will prevent a high buildup of hydrocarbons and CO_2 in the high pressure column sump or reboiler should be specified for the individual plant. Safe liquid holding times will vary considerably with process cycle, and column liquid should be dumped when hydrocarbon concentrations become significant. The subject of safe holding time and allowable concentrations is given in Section IV, F, 4f. During a shutdown, the plant should be kept closed from the atmosphere, except for the venting of excessive pressure buildup in the low pressure column, and a positive pressure maintained so as to prevent introduction of atmospheric moisture. When the shutdown is because the concentration of CO_2, acetylene, and other hydrocarbons is above the established maximum limits, the plant should be shut down, all liquid should be immediately drained, and the plant should be defrosted.

c. Liquid Disposal - Any necessary liquid drainage from an air separation plant must not be drained onto the plant floor or ground, but must be piped to an appropriate disposal system. This would include types that employ a liquid spray header in the cooling tower for discharge and those that consist of a dump tank with a suitable vaporizing or spray disposal system. Liquid disposal and defrost exit gas piping configurations may require attention to avoid any possible contact in the disposal tank of oxygen-rich liquid and defrost gas which may contain high quantities of hydrocarbons, especially acetylene. Any large gaseous oxygen or nitrogen blowoffs should be conducted outside, preferable upwards. When blowoffs are outside, large blowoff concentration of oxygen or nitrogen in confined areas, work areas, or adjacent to intake ducts must be avoided.

d. Plant Defrost - Defrost schedule depends on plant type, location, and operating history, but should be carried out at least once every 2 years.

Following plant shutdown, all liquid should be drained and vaporized. Each and every vessel and line, including process, purge, drain, and sample, should be warmed up evenly with a flow of defrosting gas, preferably dry and oil-free. Consideration should be given and care taken to avoid excessive thermal stresses. During defrost of the columns, particular care should be taken to ensure that lines to any of the safety devices are clear and free of water that could freeze and render the safety device useless, especially in cold weather. This may involve removal or manual opening of all relief valves near the end of the defrost so as to allow warm dry air to flow through the line for several minutes. Thaw temperatures should be consistent with materials of plant construction and as a general rule, should not exceed 180 F. Temperatures as low as 150 F may be preferable with plants that have copper piping and soft solder joints, as aging may have reduced the strength of the joints. To ensure complete water removal, adsorbent filters must be reactivated at temperatures from approximately 300 F to 500 F depending on the type of adsorbent and design. The dew points of the exit gases should be checked and a recommended minimum dew point of minus 70 F should be achieved.

When defrosting gas is heated by an electric heater, it is essential that a flow switch or suitable temperature switch interlock be included that would sense a loss of flow to the heater and thus prevent a possible fire.

6. Maintenance Program

The following maintenance program is quite general and is meant to be representative of the type of program that should be established for a particular plant. The frequency of inspection or maintenance given in this section are suggestions. The actual frequency applied is a function not only of the type of equipment, but also its history, process, usage, vendor, and construction which may dictate more or less frequent checking requirements. Large pieces of equipment, such as air and oxygen compressors will have a manufacturers recommended maintenance schedule.

a. Structure - Structural inspection should be made on a yearly, monthly, or daily basis depending on the equipment and the location. The general condition of the piping system including pipe supports for overloading, deflection, and cracked welds as well as excessive stress and rigging are inspected visually as a daily task. The general condition of enclosures of pumps and cold piping, that is, cold boxes and cold piping duct work, are inspected periodically. Overpressure protection devices are provided on these systems. The number and kind of devices and set pressure are based on the configuration, pressure rating, purge pressure, and the type of insulation used in the box.

b. Leaks - Major liquid and cold gas leaks are repaired immediately because of possible foundation heaving, overpressurizing of the jacket, or cracking of carbon steel structural members. First indications of leaks are frost spots and changes in purge pressure or cold vapors. A detailed procedure is given for cold box leaks in Section IV, F, 4h. Should the leak occur in a coded vessel, pneumatic or hydrostatic testing must be made of the repairs.

c. System Instruments and Controls - System instrument and control checks in operations are continuous as readings are taken on an hourly basis and a malfunction of most of them will give an alarm and/or shutdown of related equipment.

- All safety valves, regardless of service, should have an annual visual, in-place inspection for leakage, breakage of seals, and evidence of tampering, presence of a vendor tag with the set pressure legible, and general condition.
- Air compressor safety valves should be checked biannually.
- Safety valves which are icing up due to leakage must be repaired or replaced immediately. If icing is caused by a heat leak, the insulation or piping should be repaired.
- Burst disks should be inspected for signs of corrosion or cracking.

d. Insulation - Insulation check and inspection is accomplished on a daily basis.

e. Liquid Oxygen Pumps - Pumps should be checked as follows:

- The pump seal (or packing) should be inspected for leakage. Unusual noise or vibration should be noted, and the nitrogen flow should be checked. These tasks should be done daily or each shift.
- The pump box should be checked for frost spots (weekly to monthly) and oxygen concentration (weekly).
- The condition of blowout panels on the box should be checked (weekly to every 6 months).
- The pump should be defrosted and the suction screens should be inspected and cleaned every 3 months to a year.

- The oxygen box pump should be solvent washed and a check of the entire pump assembly should be performed every 1 to 3 years.

f. Vaporizers - Vaporizers should be checked as follows:

- All stream piping valves and fittings should be inspected for leaks and steam drain lines and traps should be checked for plugging on a daily to weekly basis. The steam regulator valve and condensate trap should be checked every 3 months.

- The product oxygen coil should be pressure tested each month.

- During freezing weather check the water bath temperature, heater on at ~35 F and off at ~40 F, and the panel heater operation each day.

- The vaporizer should be washed internally with an approved solvent (e.g., methylene chloride) about every 4 years.

7. Safety Check List for Cryogenic Air Separation Plants

a. Air Intake Filter

- The filter should be located so that venting oxygen and excessive water vapor from the cooling tower will not enter the filter. No parking should be permitted near the filter to prevent automobile engine fumes from entering the air intake.

- Filters should be cleaned periodically.

b. Air Compressors

- Lubrication rates and air discharge temperatures should be within manufacturers' recommendations.

- Coolers should be inspected periodically for corrosion.

- The compressor pad should be sealed and free of cracks.

c. Cold Box

- The cold box should be tested weekly for oxygen concentration. Corrective action should be taken if the oxygen concentration exceeds 21%.

- The N_2 purge should be adequate (5 psig; 2 psig if the supply is large, e.g., from the low-pressure column).

- The cold box should be free of frost spots.

- All valve boots and valve panels should be sealed. All removable panels should be tightly sealed with an approved sealer.

- The cold box foundation should be heated to prevent freezing and heaving of the subsoil, and the pad should be maintained in a crack-free condition.

- If the plant is shut down for 24 hours or longer, all crude and pure liquid oxygen should be drained from the equipment.

- If the liquid level in the reboiler will drop below one-fourth the normal level, the liquid should be drained.

d. Hydrocarbon Adsorbers

- The reactivation gas should be 90 percent purity (or better) nitrogen.

- If a bypass for the adsorbers has been provided, it should be used only during startup.

- The adsorber filter should be inspected periodically and the proper activation cycle and recommended reactivation temperatures should be used.

e. CO_2 Filter

- The reactivation gas should be 90 percent purity (or better) nitrogen.

f. Liquid Oxygen Pumps

- If the subcooling medium is oxygen, the coolant side of the subcooler should be blown down periodically to prevent accumulation of hydrocarbons.

- The jacket should be free of frost spots.

- The pump box [illegible] be tested weekly for oxygen concentration.

- If the air supply to the main heat exchangers is stopped, the oxygen pump should be shut down to prevent exposing carbon steel lines downstream of the exchanger to temperatures below -20 F.

g. Expanders

- The area should be free of oil traces from leakage and misting from breathers or vents.

- Expander-loader drives should be guarded and the overspeed protection device should be in operable condition.

h. Turbo Expander

- The interlock to shut down the oil pump on low pressure seal air should be functioning properly.

- If belts are used between the loading device and the engine, they should be in good condition.

i. Expansion Engine Oil Separator and Filter

- The filters should be inspected periodically.
- Piping should be designed so that the oil separator and filter cannot be bypassed.

j. Interconnecting Piping

- Insulation used on oxygen lines should be of an approved type.
- All sealants other than Teflon ribbon should be prohibited for oxygen service.
- All lines operating below -20 F (during normal operation, cold shutdown, and even plant upset) should be constructed of nonferrous or austenitic stainless steel unless low temperature alarms are provided where carbon steel piping temperature could accidentally go below -20 F.
- All vents should be positioned such that cold liquid or gases will not discharge into operating areas or impinge on equipment, piping (especially carbon steel piping), or power lines.
- High pressure lines and vessels should be relieved of pressure prior to working on lines.

k. Instrumentation

- All high pressure gauges (100 psig and over) should be equipped with blowout plugs or backs and plastic fronts.
- All oxygen safety valves should be headered outside the building or vented directly outside the building, and all safety valve vents should be positioned such that cold liquid or gas will not discharge into operating areas or impinge on equipment, piping, or power lines.
- Safety valves must be protected from extreme weather (freezing rain and snow) to prevent inoperability.
- Safety valves should be inspected and cleaned at least once a year.
- Safety valves must be installed in a vertical position. (Malfunction may result if installed in other than the vertical position.)
- Leaking safety valves must be repaired or replaced promptly.
- Plastic fronts should be used on instruments to prevent shattering and injury to personnel.

- An oxygen analyzer should be available and in good condition.

l. Hydrocarbon Testing

- Test for acetylene should be performed daily on the fluid from the reboiler condenser and weekly on liquid oxygen storage. The presence of acetylene should result in immediate corrective action (plant shutdown is required by responsible authority if results show 2 ppm).

- A total hydrogen analysis is required of the reboiler liquid or product line if representative of reboiler liquid and of the high pressure air stream after CO_2 removal and prior to any liquefaction. The analysis is optional on the crude oxygen line downstream of the hydrocarbon adsorber.

- Any upward trend of hydrocarbon concentration deviating from the established normal range must be investigated, and corrective action is required.

- Plant shutdown, dumping of liquid, and corrective action to eliminate cause is required by responsible plant authority if the hydrocarbon concentration increases above 500 ppm (this limit is lower for plants located in areas where low solubility hydrocarbons are present in the atmosphere due to neighboring industries).

m. Material Storage

- All chemicals and oils should be properly labeled and the intended use for the various materials should be noted.

- Solvent and paint storage must be segregated from less volatile material and from oxygen equipment and piping.

- No Smoking or Open Flame signs must be posted.

- All spare parts must be labeled with the appropriate material code number and stored in an orderly manner.

- Hydrocarbon decontaminated parts should be sealed to prevent recontamination.

- Spare parts should be carefully examined prior to installation to determine their adequacy for temperatures and pressure they will be subjected to.

- All threading sealants, packing materials, etc. not approved for oxygen service should be disposed of or tagged: "Do Not Use in Oxygen Service."

n. Safety Equipment

- The following safety equipment should be provided and used: gloves, safety glasses with side shields, chemical goggles, face shields, approved flashlights, (M.S.A. permissable or equal), explosion-proof hand lamps, first aid supplies, stretchers, gas mask, or blower mask and respirators.

o. Plant Operations

- Up-to-date operating handbooks should be available and used.
- Plant management should be familiar with state and local codes.
- Safe plant operation should be reviewed regularly with plant operators.

G. STORED LIQUID OXYGEN

For smaller sewage treatment plants, where oxygen requirements are not large enough to warrant the installation of an oxygen production plant, the oxygen requirements can be satisfied by periodically trucking in liquid oxygen to a cryogenic storage tank. The storage tank is equipped with a vaporizer to supply gaseous oxygen for sewage treatment. Even sewage treatment plants with their own cryogenic or molecular sieve adsorbent air separation plants will require liquid oxygen storage tanks for emergency supply or for those brief periods when the oxygen demand may exceed the capacity of the air separation facility. A typical oxygen storage tank is shown in Figure 46.

1. Design Considerations

The transfer of liquid oxygen from the air separation plant to storage is normally accomplished through gravity feed to low-pressure tanks operating at 2 to 3 psig. Piping material may be austenitic stainless steel, copper, or aluminum. Either rock wool or cellular glass insulation can be used.

The liquid oxygen is stored in specially designed tanks ranging in size from several hundred gallons to several thousand tons depending on the needs of the installation. These tanks require special insulating techniques because of the low temperatures involved. The most frequently used insulating techniques are:

1. Single walled tank placed in second container (tank or building) with the annular space filled with insulation and purged with dry nitrogen.
2. Double tank construction with powder-vacuum or superinsulation-vacuum in the annular space.

With the materials of construction and fabricating techniques now available, the possibility of catastrophic failure (brittle failure) of tanks storing cryogenic liquids or of the vaporizer and related piping, is essentially non-existent. These systems, however, should be designed and fabricated only by those knowledgeable in this technology, the applicable codes, and the industry's experience to ensure their safety and integrity.

All tanks should be protected against overpressure. Some tanks, because of design and service, may require underpressure protection.

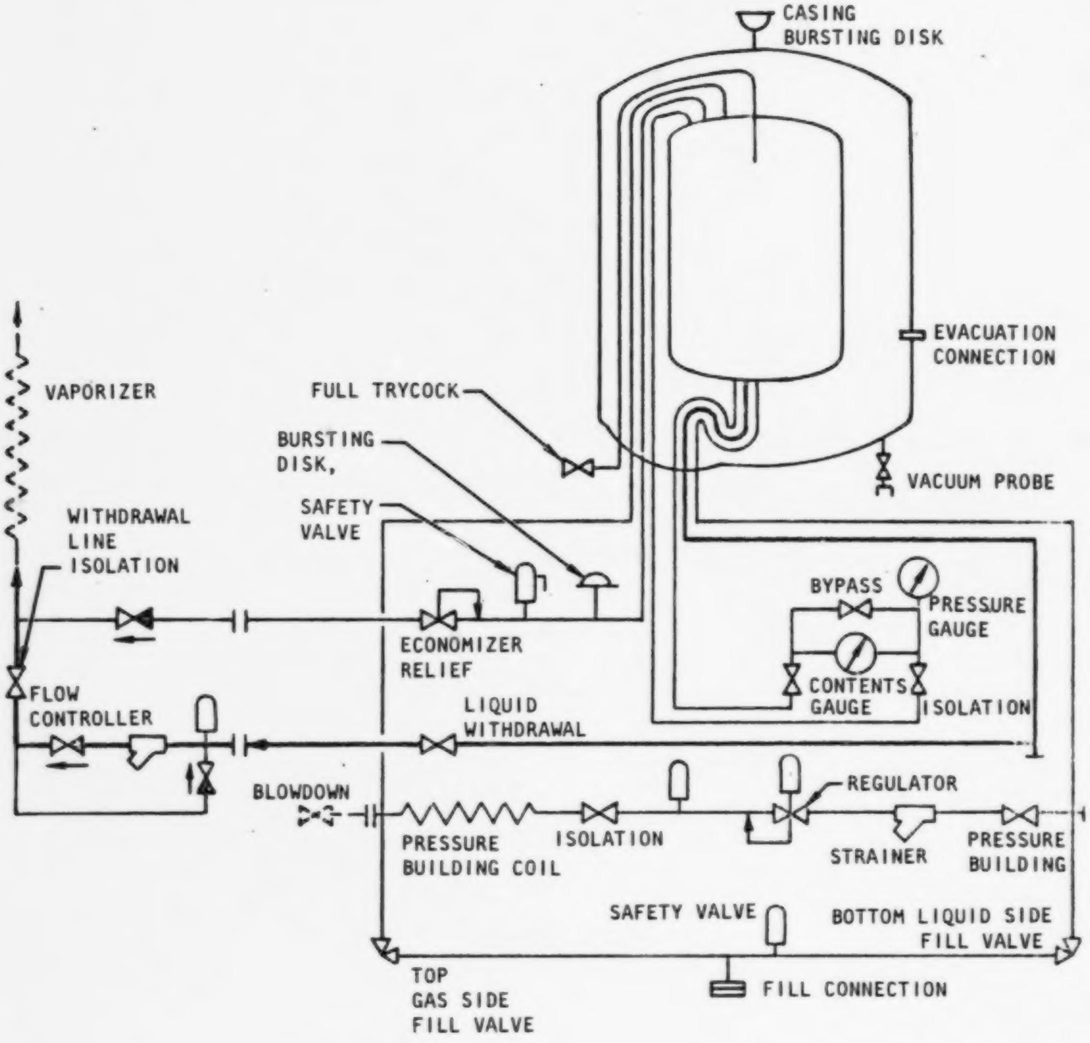
CASING
BURSTING DISK
EVACUATION
CONNECTION
FULL TRYCOCK
VAPORIZER
BURSTING
DISK,
VACUUM PROBE
WITHDRAWAL
LINE
ISOLATION
SAFETY
VALVE
BYPASS
PRESSURE
GAUGE
ECONOMIZER
RELIEF
FLOW
CONTROLLER
CONTENTS
GAUGE
ISOLATION
LIQUID
WITHDRAWAL
REGULATOR
BLOWDOWN
PRESSURE
BUILDING COIL
ISOLATION
STRAINER
PRESSURE
BUILDING
SAFETY VALVE
BOTTOM LIQUID SIDE
FILL VALVE
TOP
GAS SIDE
FILL VALVE
FILL CONNECTION

Figure 46. Schematic Flow Diagram of Typical Cryogenic Liquid Storage Tank

To insure that each liquid storage and vaporization system is installed in a safe location, the following design features shall be used.

- A concrete pad shall be installed under the storage tank. The vaporization system may be installed on concrete piers on footings, separate from the pad and curbs.
- If tanker trucks will be used to supply oxygen for sewage treatment as a backup in case the air separation plant needs to be shut down for maintenance, a concrete wheel stop shall be installed to prevent backing a tanker into the storage tank, vaporizer or piping. The wheel stop may be a part of the curbing.
- A concrete curb should be installed around the pad to contain accidental spillage during loading operations. Asphalt or combustible paving should be excluded where there is possible contact with liquid oxygen spills. An adequate water supply and chemical fire extinguishers should be readily available.
- Deluge systems should be used at cryogenic liquid loading facilities where daily transfer operations are conducted on a routine basis. A spray nozzle should be provided at each liquid loading connection. The adjustment of the nozzle depends on available capacity and pressure of fire water system. The nozzle pattern should be set for full coverage of the rear of the trailer with sufficient angle to allow for the trailer to be spotted off center from the loading connection. The system should be provided with an air operated block valve which is actuated from at least two remote positions or a manual valve when the valve can be located in a safe operating area.

2. Loading and Unloading Cryogenic Tankers

Experience indicates that spills and leakage that occur are usually limited in size and usually occur during liquid transfer, as (1) rupture of hose, (2) loose connection hose-to-pipe, or hose-to-trailer, and (3) valve failure.

The safety precautions to be exercised in the loading and unloading of cryogenic trailers are listed below:

- Vehicles shall not enter an area containing an oxygen enriched atmosphere or a flammable gas atmosphere. Also, vehicle engines shall not be started in any atmosphere suspected of containing a high oxygen concentration or a flammable gas. A vehicle shall not enter a loading area until permission has been granted by the personnel responsible for the loading operation. Permission will be given after ascertaining that the immediate area is not hazardous due to venting trailers. Similarly, a vehicle engine shall not be started in preparation to move a trailer until permission has been granted by the personnel responsible for loading operation. At no time is the engine to be started or allowed to run during loading or unloading of the trailer.
- Wheel chocks are required in place, in addition to locking brakes when parking a trailer.

- Oxygen loading and unloading is prohibited in the vicinity of simultaneous loading or unloading of gaseous or liquid fuel.

- There shall be no smoking, sparks, or open flames within a minimum distance of 100 feet of loading or unloading for a flammable liquid or liquid oxygen. The tractor ignition switch and light circuit must be turned off during loading or unloading operations.

- A driver shall not go into a loading area which he considers to be unsafe. He shall immediately contact his supervisor and explain the unsafe condition in detail.

- Loading and unloading operations shall not commence or continue if a leak develops or if any condition exists which would be hazardous to the transfer operation. It is prohibited to hammer a transfer hose connection while transfer is being made.

- Steam or hot water should be used to thaw frozen piping or equipment. Frozen valves should be thawed by directing water on the valve bonnet and extension below the packing nut. Never direct water on the packing nut or packing area.

- Personnel loading and unloading liquid tanks shall report to their supervisor any foreign deposits observed in transfer hoses or in fill and drain connections.

- Prior to disconnecting a liquid transfer line, the line shall be drained; never assume a line has been drained by another person.

- In the event of a liquid spill while transferring liquid, the trailer shall be checked in detail for damage, such as frozen tires, fractured metal, etc., prior to moving the trailer.

- The transfer, drain, and fill lines should be capped at all times when not in use. Transfer hoses should be hydrostatically tested every 6 months.

- Prior to starting the tractor engine, the driver shall make a complete circuit of the trailer to ensure the transfer line is disconnected, electric grounds are removed, wheel chocks are removed and stored in their proper location, and compartment doors are closed and latched.

3. Operation

a. Control System - Liquid is normally supplied to the vaporizer through the liquid withdrawal line, Figure 46. To compensate for the lowering of tank pressure as liquid is withdrawn, a pressure regulator allows a regulated flow of liquid to flow by gravity to the pressure building coil. The vaporized liquid is returned to the tank to provide the driving force for uninterrupted pipeline withdrawal.

During periods of low withdrawal, or after a period of no withdrawal, the economizer circuit becomes operational when tank pressure increases to the setting of the economizer relief valve. Then when pipeline withdrawal occurs, gas flows through the economizer relief valve, its downstream check valve, and into the vaporizer.

The heart of the economizer circuit is a spring-loaded flow controller. This flow controller remains open when its upstream pressure exceeds its downstream pressure by more than 10 psig; thus, liquid is delivered to the vaporizer. When the economizer relief valve opens, venting gas to the delivery line, the pressure differential across the flow controller becomes less than 10 psig causing the flow controller to close, thus cutting off liquid flow. When withdrawal of excess pressure from the tank is complete, the economizer relief valve closes, the flow controller opens, and liquid delivery to the vaporizer is resumed. A line relief check valve provides a relief path to the tank for the liquid trapped downstream of the flow controller when withdrawal is stopped.

b. Filling - The following procedures should be adhered to during initial fill and normal fill:

- Initial Fill

  NOTE: All valves are to be closed except the isolation valves for the pressure gauge (Figure 46)

  1. Open the blowdown and full trycock valves and blow down the pressure to about 5 psig. Keep the full trycock valve open.

  2. Remove the blank flange from the fill connection and connect the fill hose to the connection.

  3. Open the top (gas side) fill valve completely and start filling the tank as rapidly as possible.

  4. Close the bottom (liquid side) fill valve after the residual liquid in the fill hose has vaporized.

  5. Relieve the pressure in the fill hose by slightly loosening it at the fill connection, then disconnect the fill hose and reinstall the fill connection blank.

4. General Considerations

Operators required to work with these containers, even those who must work near them as part of the workday environment, must learn the peculiarities and valving arrangements of particular installations. If, the tank is the property of the liquid oxygen vendor, the vendor shall instruct the customer's engineer as to the function of the tank and clearly designate the valves he has to manipulate during ordinary operation and during unusual or emergency situations. All valves that must be shut in an emergency operation should preferably be painted red.

Oxygen storage tanks must have their contents checked weekly for acetylene. If the slightest trace of acetylene is detected, the plant engineer shall be notified immediately.

Never overfill a storage tank. At least 5 percent of vapor space must be maintained for the vessels. Consult the vendor's literature or the operating instructions for specific equipment limitations. In the absence of other instructions the storage of cryogenic liquids in tanks should be limited to the following capacities:

Operating Pressure	Percent Vapor Space
Below 40 psig	5.0
40 to 80 psig	7.5
Above 80 psig	10.0

It is important to check the pressure in the insulating jacket of a cryogenic storage tank. Pressure between 50 and 200 microns is adequate. Should the pressure build up beyond 200 microns, the vacuum should be restored by means of a vacuum pump. Should the insulating vacuum deteriorate, increased heat gains will occur resulting in pressure buildup and perhaps appreciable loss of gaseous oxygen through pressure relief valves. A burst disk is provided as a pressure relief device.

5. Vaporizer

Liquid oxygen must be converted to a gas before the oxygen can be used for sewage treatment. The conversion process occurs in a vaporizer which usually consists of a copper coil immersed in a bath of recirculating or electrically heated water or of steam.

A temperature sensor should be located downstream of the vaporizer to sound an alarm if the oxygen gas temperature falls below a specified temperature. The alarm indicates that either the vaporizer system is failing or that its capacity is being exceeded. In either case the temperature sensor should automatically regulate the liquid oxygen feed valve to prevent low temperature oxygen gas (or liquid) from reaching the carbon steel piping.

6. Safety Check List for Stored Liquid Oxygen

a. Liquid Oxygen Storage

- A general inspection of the liquid oxygen storage tanks should be conducted anaually. This inspection should include foundations, supports, insulation, vacuum readings, and general condition.
- Check valve packing for leaks and inspect boosts on extended stem valves daily to weekly.
- Inspect relief valve for leakage daily.

- Check the liquid oxygen storage for the presence of acetylene weekly.

- Check the storage tank outer shell for frost spots weekly.

- Personnel should be forbidden to enter empty storage tanks until the atmosphere has been determined to contain a minimum of 18 percent and a maximum of 25 percent oxygen.

- Safety belts and life lines should be worn when entering a tank, and a person outside should man the life line at all times.

- Welding inside tanks is forbidden unless there is positive ventilation of the tank or a self-contained breathing apparatus is provided.

b. Liquid Transfer Area

- A minimum of 12 feet of concrete pad should be provided on the trailer side of the trailer wheel stop.

- The concrete pad should be sloped to permit flow of liquid to the least hazardous area.

- The concrete pad should be maintained free of cracks which would tend to permit the accumulation of dirt and grease.

- An adequate trailer wheel stop must be provided.

- Transfer hose should be hydrostatically tested every 6 months.

- A fire water protection system should be provided and should be periodically checked.

c. Vaporizers

- All steam piping valves and fittings should be inspected for leaks and steam drain lines and traps for plugging on a daily to weekly basis. The steam regulator valve and condensate trap should be checked about every three months.

- Pressure test the product oxygen coil every month.

- During freezing weather, check the water bath temperature, heater on at $\sim$35 F and off at $\sim$40 F and the panel heater operation every day.

- Wash the vaporizer internally with an approved solvent (e.g., methylene chloride) about every 4 years.

H. BIBLIOGRAPHY

Lapin, A., Liquid and Gaseous Oxygen Safety Review Vol. I, II, III, and IV, NASA CR-120922 APCI TM 194 (1972). (Data from Air Products and Chemicals Inc.)

Chemical Rocket/Propellant Hazards, Vol. III, Chapter 18, Liquid Oxygen CPIA Publication No. 194, May 1970, JANNAF Propulsion Committee (Data from Rocketdyne)

Safe Practices Guide for Air Separation Plants, Compressed Gas Association, Inc., New York, N.Y.

Oxygen, Pamphlet G-4, Compressed Gas Association, Inc., New York, N.Y., Sixth Edition, 1972

Equipment Cleaned for Oxygen Service, Pamphlet G-4.1, Compressed Gas Association, Inc., New York, N.Y. (1959)

Industrial Practices for Gaseous Oxygen Transmission and Distribution Piping Systems, Pamphlet G-4.4, Compressed Gas Association, Inc., New York, N.Y. (1973)

Theory of Cryogenic Air Separation, Air Products and Chemicals, Inc.

Installation and Operating Instructions, TM Storage Tanks, F-13-609-A, Linde Division, Union Carbide

Operating and Maintenance Instructions for PSA Oxygen Generation System at Speedway Wastewater Treatment Plant, Speedway, Indiana, Operator's Manual No. OM-1212 (Rev.) 1973, Linde Division, Union Carbide Corporation

Operating Instructions for the Oxygen Generating Plant for Detroit Metro Water Department at Detroit, Michigan, Vol. I, T-180 Plant Operators Manual No. 1222, 1973, Linde Division, Union Carbide Corporation

V. PERSONNEL SAFETY REQUIREMENTS

A. STAFFING

The treatment plant staff should include a qualified safety person; engineer or consultant who has acquired all of the necessary safety knowledge to be generally responsible for safety matters and in particular instruct plant personnel in all safety aspects of oxygen aeration sewage treatment plants.

The treatment plant should be adequately staffed in terms of number of operators. Backup personnel should be available for all phases of specific hazardous tasks.

B. INDOCTRINATION

Each operator should be familiar with the chemical and physical characteristics of liquid oxygen, and should know what to do in any emergency related to handling liquid oxygen. Also, the operator should be completely familar with the problems and corrective action spelled out in the treatment plant sections of this manual.

All new personnel should receive a thorough indoctrination on all procedures listed in this manual prior to being given an assignment in the treatment plant.

C. IN-PLANT SAFETY MEETINGS

In-plant safety meetings should be held every week for the purpose of continuously reviewing and updating the safety practices in this manual. This should include writing new material to accommodate new procedures and equipment. A log should be maintained on the material covered in the meeting.

The meetings generally should cover the use of equipment, use of oxygen, spills, cleanups, and other safety matters. Operation of each unit process and how to prevent upsets that could cause hazardous conditions should also be discussed.

In addition to covering preventive material, information on any recent accident should be covered in every detail. Knowing how and why an accident occurred may well be the best way to prevent future accidents.

A safety bulletin board should display safety literature, current safety information, actions taken in safety meetings, and announcements of future meetings.

D. SAFETY EQUIPMENT

The plant safety equipment may be divided into that used for the following:

- Air monitoring
- Liquid monitoring
- Venting

Personal safety equipment includes:

- Gloves
- Safety glasses with side shields
- Chemical goggles
- Face shields
- Self-contained air breathing masks
- Approved flashlights
- Explosion-proof hand lamps

All personnel should be made intimately familar with the proper uses of all safety equipment. Demonstrations of its use should be performed at least once per month or more often as the need arises.

E. FIRST AID AND MEDICAL SERVICES

All personnel should be trained in first aid. First aid supplies and equipment, including respirators and stretchers, should be on hand in one or more clearly marked and known locations. Arrangements for emergency medical services should always be kept current. Names, phone numbers, and addresses of medical doctors on call, ambulance services, and emergency hospitals should be prominently posted in several locations.

F. FIRE FIGHTING EQUIPMENT

An adequate number of fire hydrants should be located in the plant area or adjacent to the plant. All fire hoses should be hydrostatically tested to 150 psig (or other specified pressure) every 12 months. Fire hoses should be accessible and maintained in good operable condition. Fire blankets should be available, mounted in canisters on walls, and in accessible locations.

An adequate number of fire extinguishers should be provided in the plant, and be visually inspected every month. In addition, an inspection of fire extinguishers should be made every month for:

- Broken seals
- Full weight or liquid level
- Condition of hose
- Pressure gage, if applicable
- Nozzle
- Ticketing

All personnel should be trained in the use of fire extinguishers. A private fire brigade should be organized if the treatment plant is large enough to warrant such a practice. The phone number of the local fire fighting organization should be prominently displayed in several locations. The local fire department should be contacted to determine what equipment they have available and to familiarize them with potential hazards in the plant.

G. MAINTENANCE OF EQUIPMENT

Specified persons only should have the responsibility of maintaining and checking safety, first aid, and fire fighting equipment. It is important that these be specific assignments.

H. IN-PLANT SAFETY TEAMS

A Safety Team should be established within each plant. The team should be responsible for the review of work practices to establish safe procedures. All new work procedures should have the approval of the Safety Team prior to implementation. Once a new procedure is adopted, it should be reviewed on a routine basis along with all other procedures.

APPENDIX

OXYGEN COMBUSTION HAZARDS

Evaluation of the combustion or explosion hazard in oxygen aeration activated sludge reactors requires examination of the oxygen-wastewater system with regard to the simultaneous presence of (1) oxidizing materials, (2) fuel or combustible materials, and (3) ignition sources. For an incisive discussion of this problem, McKinley (Ref. A-1) may be quoted verbatim:

"The oxygen-wastewater system has the following significant elements

a.	the gas phase:	the gas phase is at atmospheric pressure and consists of oxygen mixed with carbon dioxide, nitrogen, water vapor, and traces of other gases.
b.	the liquid phase:	the liquid phase is primarily water containing a suspension of micro-organisms the concentration of micro-organisms typically ranging from 1/3 to 3/4 weight percent.
c.	the walls:	the basin covers and walls are in contact with liquid or gas and provide a surface on which biological floc, grease, or other solid matter may build up
d.	the machinery:	this portion of the system consists of all the moving parts, such as aerators, bearings, recycle pumps (and compressors).
e.	the oxygen supply system	
f.	the people	

It is the interaction of all of these system elements which must be examined in an analysis of any potential oxygen enriched atmosphere hazard.

As we methodically proceed with the hazards evaluation for a system, looking for fuel and ignition sources, we will do so with a variety of very practically oriented questions in mind, such as:

1. If a localized fire starts will it spread or will it go out?
2. Is sufficient fuel present to cause a problem if it completely burns?

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As we methodically proceed with the hazards evaluation for a system, looking for fuel and ignition sources, we will do so with a variety of very practically oriented questions in mind, such as:

1. If a localized fire starts will it spread or will it go out?
2. Is sufficient fuel present to cause a problem if it completely burns?

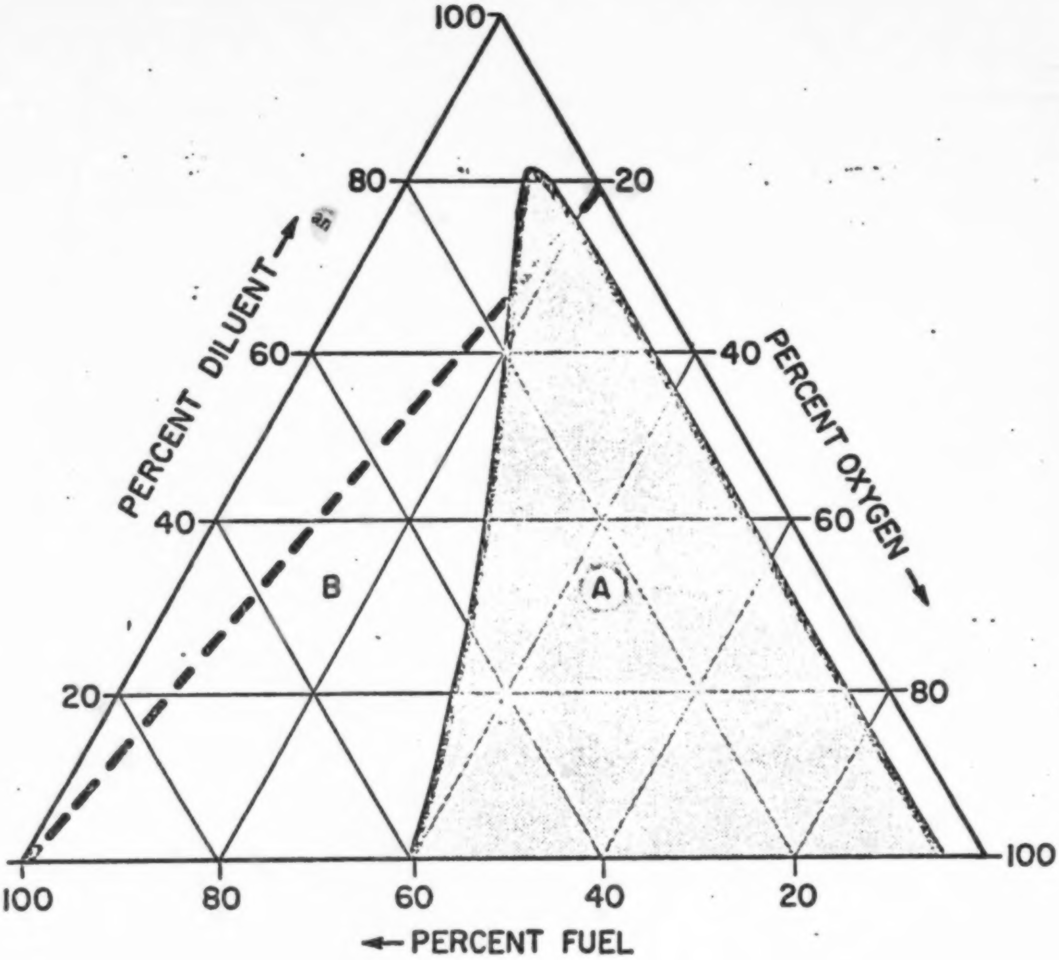
3. Is there any way for an explosion to occur?
4. Is it possible for a soluble liquid or gas to enter the system with the wastewater feed and become concentrated inside the system to a concentration level which would be hazardous?
5. Can floating solid or liquid fuels enter the system and become a problem at the liquid-gas interface?

The classical oxygen-fuel-diluent triangle provides understanding of the oxygen enriched atmosphere hazards relative to the oxygen activated sludge operation (Figure A-1). Each corner represents 100% concentration of the component: oxygen, or fuel, or diluent. In a practical and complex system, such as in our case, the fuel may be a mixture and several diluents may be involved. By adding the behavior of these together we may make a simplified representation to show whether the system is in a safe region of operation as indicated by area B or in an unsafe area, as indicated by area A. Our safety objective must, of course, be to understand our system sufficiently well that essentially all parts of it are always operating in area B and not in area A. In area B, even if ignition energy is supplied the flame cannot propagate - it will die out. In area A flame propagation will occur - explosive energy release may result."

For any potentially explosive mixture, a combustible-lean limit and a combustible-rich limit exist, referred to as the lower explosion (or flammability) limit (LEL) and the upper explosion (or flammability) limit (UEL). A numerical example for the methane/oxygen/nitrogen system is shown in Figure A-2, taken from Ref. A-2, based on References A-3 and A-4. From this, it is seen that for the methane/oxygen system LEL = 5.1% methane, and UEL = 61% methane. At the nitrogen diluent concentration of 21% the air composition is reached, for which LEL = 5% methane and UEL = 15% methane. Now in the oxygen aeration activation sludge system it is the LEL which is the characteristic of interest. Figure A-2 and Table A-1 indicate that LEL values are fairly constant regardless of the amount of diluent added, and that, in particular, LEL values in air and oxygen are very close. (Figure A-2 shows that this is not true for UEL values.) Table A-2 shows additional flammability limits as well as minimum oxygen concentrations for universal flammability (see Figure A-1), computed by Baker and Carlson (Ref. A-2).

When flammable mixtures are formed by accident, it is usually desirable to reduce the combustible concentration quickly by adding enough air or inert gas to lean out the mixtures into the non-flammable region. The addition of increasing amounts of a chemically inert substance to the mixtures causes the lean and rich limits to approach each other and ultimately meet. A comprehensive study of the effect of several diluents (carbon tetrachloride, carbon dioxide, nitrogen, helium and argon) on methane limits in air is described by Coward and Jones (Ref. A-3). The extinctive efficacies of the diluents in decreasing order are

$$CCl_4 > CO_2 > N_2 > He > A.$$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PERCENT DILUENT
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PERCENT FUEL
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Figure A-1. Classical Oxygen-Fuel-Diluent Composition Diagram (from Ref. A-1)

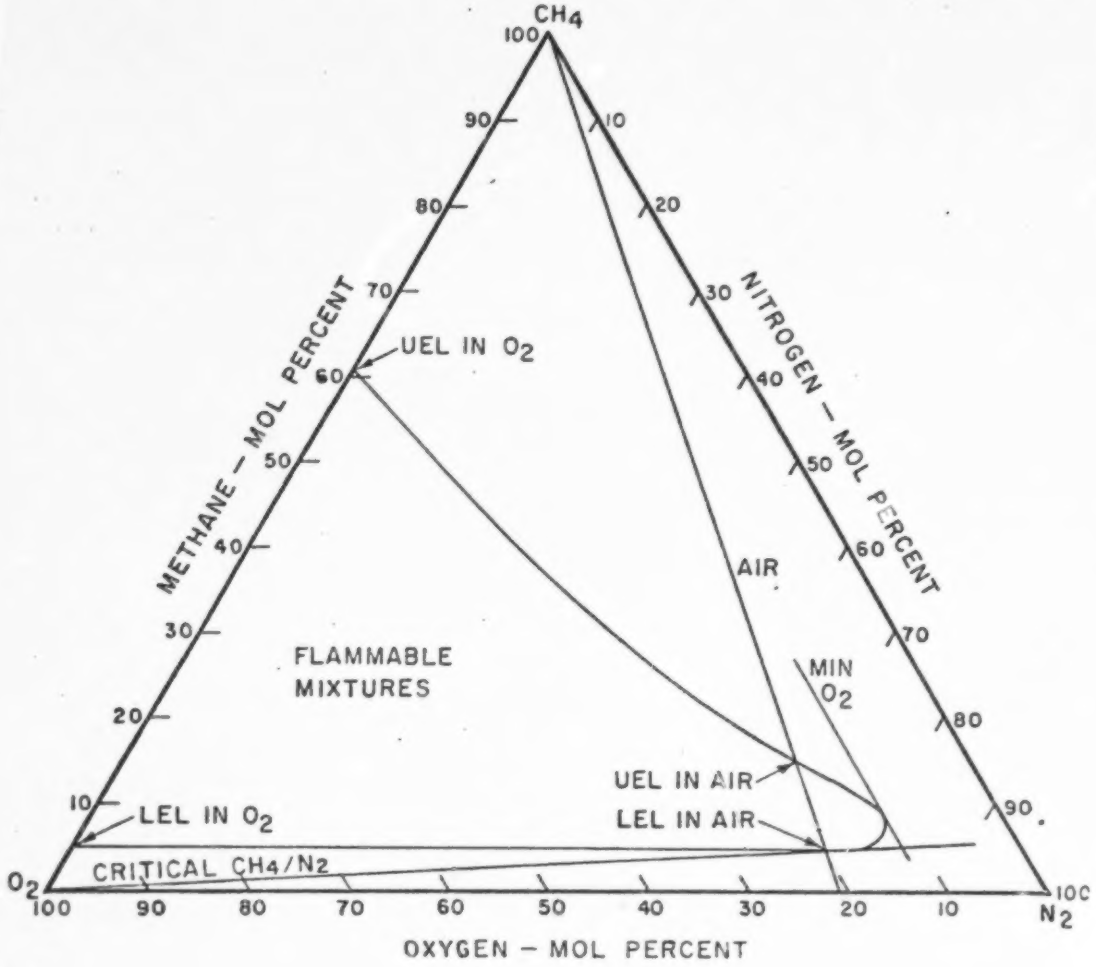

Figure A-2. Flammability Diagram for $CH_4/O_2/N_2$ System (From Ref. A-2, A-3 and A-4)

TABLE A-1. LOWER LIMITS OF FLAMMABILITY (LEL) OF FUEL GASES AND VAPORS WITH OXYGEN AND WITH AIR (PERCENT FUEL BY VOLUME) (Ref. A-3)

Compound	Formula	Pure Oxygen	Atmospheric Air
Hydrogen	H_2	4.0	4.0
Carbon Monoxide	CO	15.5	12.5*
Ammonia	NH_3	15.0	15.0
Methane	CH_4	5.1	5.3
Ethane	C_2H_6	3.0	3.0
Ethylene	C_2H_4	3.0	3.1
Propylene	C_3H_6	2.1	2.4
Cyclopropane	C_3H_6	2.5	2.4
Diethyl ether	$C_4H_{10}O$	2.0	1.9
Divinyl ether	C_4H_6O	1.8	1.7

TABLE A-2. FLAMMABILITY LIMITS OF GASES IN OXYGEN OR AIR
(from Ref. A-2 based on Ref. A-3)

	Flammability Limit, % (* in air)		Oxygen % below which no mixture is flammable with air diluted by	
Gas	Lower	Upper	N_2	CO_2
Hydrogen	4.0	94	5.0	5.9
Carbon Monoxide	15.5	94	5.6	5.9
Methane	5.1	61	12.1	14.6
Ethane	3.0	66	11.0	13.4
Propane	2.3	55	11.4	14.3
Butane	1.8	49	12.1	14.5
Isobutane	1.8	48	12.0	14.8
Pentane	1.5*	--	12.1	14.4
Hexane	1.2*	--	11.9	14.5
Heptane	1.2*	--	----	----
Octane	1.0*	--	----	----
Nonane	0.8*	--	----	----
Ethylene	3.0	80	10.0	11.7
Propylene	2.1	53	11.5	14.1
Butylene	2.0*	--	----	----
Acetylene	2.5*	--	----	----
Benzene	1.4*	--	11.2	13.9
Toluene	1.4*	--	----	----
Styrene	1.0*	--	----	----
Cyclopropane	2.5	60	11.7	13.9
Methanol	7.3*	--	10.3	13.5
Ethanol	4.3*	--	----	----
Ethyl Ether	2.0	82	----	----
Acetone	3.0*	--	13.5	15.6
Gasoline	1.4*	--	11.6	14.4
Kerosine	0.7*	--	----	----
Naphtha	0.8*	--	----	----

The experiments producing these results were carried out in tubes of 5 cm diameter. In tubes of smaller diameter, helium increases in efficacy due to its very high thermal conductivity, otherwise the effects correspond closely to the specific heats of the diluents. For tests in air with JP-4, a distillate fuel, and nitrogen and carbon dioxide diluents at 70 F at various pressures, Stewart and Starkman (Ref. A-5) report that there is little or no difference between these inertants in their effect on the lean limit.

In regard to mixtures of several flammable gases and vapors, a simple formula, of additive-character, was advanced by Le Chatelier (Ref. A-6) to connect the lower limits of two gases with the lower limit of any mixture of them. It is

$$\frac{n_1}{N_1} + \frac{n_2}{N_2} = 1,$$

in which N_1 and N_2 are the lower limits (volume percent) in air for each combustible gas separately, and n_1 and n_2 are the percentages of each gas in any lower limit mixture of the two in air.

The formula indicates that, for example, a mixture of air, carbon monoxide, and hydrogen, which contains one-quarter of the amount of carbon monoxide and three-quarters of the amount of hydrogen necessary to form a lower-limit mixture, will be a lower-limit mixture. If the formula is true, the lower limits of flammability form a series of flammability equivalents for the individual gases of a mixture. The formula also indicates that lower-limit mixtures, if mixed in any proportions, give rise to mixtures that are also at their lower limits. In Ref. A-3 it is stated that the formula may be generalized to apply to any number of combustible gases, thus:

$$\frac{n_1}{N_1} + \frac{n_2}{N_2} + \frac{n_3}{N_3} + \; . \; . \; . = 1,$$

which may be expressed as

$$L = \frac{100}{\frac{P_1}{N_1} + \frac{P_2}{N_2} + \frac{P_3}{N_3} + \; . \; . \; .}$$

where L is the lower limit of the mixture of combustible gases and P_1, P_2, P_3 . . . are the proportions by volume of each combustible gas present in the original mixture, free from air and inert gases, so the

$$P_1 + P_2 + P_3 + \; . \; . \; . = 100$$

For example, the lower limit of a "natural gas" of the composition

Subscript	Gas	P	N
1.	Methane	80	5.3
2.	Ethane	15	3.22
3.	Propane	4	2.37
4.	Butane	1	1.86
		100	

is given by

$$L = \frac{100}{\frac{80}{5.3} + \frac{15}{3.22} + \frac{4}{2.37} + \frac{1}{1.86}} = 4.55$$

In noting that the accuracy of the formula has been tested carefully for many mixtures, it is also stated in Ref. A-3 that while, in general, the formula is often correct or very nearly so, there are some marked exceptions. Many of the discrepancies are found with upward-propagating flames, especially when one of the constituents is a vapor, such as ether or acetone, capable of giving rise to the phenomenon known as a "cool flame". Le Chatelier's law is useful when its applicability has been proved, but it should not be applied indiscriminately. The formula has been used to represent limits for various industrial gases for which experimental data are available. Hence, it is possible to find the minimum amount of a diluent and/or the maximum amount of oxygen for nonflammability of a given gas mixture.

When a combustible liquid is added to the wastewater stream, its solubility in water determines the concentration of its vapor in the gas phase above the liquid surface (freeboard). When the tank is closed at the top, it is possible to compute vapor equilibrium concentrations using solubility data and Henry's Law for dilute solutions. Generally, for hydrocarbons, solubility decreases with increasing molecular weight. Solubility is lowest for paraffins, increasing with olefins, aromatics and acetylenes, in that order. Solubilities and Henry's Law constants of different hydrocarbons (Ref. A-7) are shown in Table A-3, taken from Ref. A-2.

The combined effect of concentration flammability, solubility, and volatility determines the combustion hazard of an ignitible substance. In Ref. A-2 numerical computations are made to show that a given quantity of benzene (which is highly soluble) causes a vapor concentration much below the LEL, while the same amount of n-octane (which is less soluble) results in a vapor concentration nearly twice that of the LEL. Table A-4, from Ref. A-2, shows what size spills of selected infinitely soluble hydrocarbons are required to produce LEL mixtures. For more volatile substances, e.g., acetone, a smaller spill is shown to be flammable, while for the less volatile alcohols extremely large spills would be necessary. This calculation method can be applied to treatment plant components upstream of the activated sludge reactor, such as the sewer or aerated grit chamber, to determine the actual gas mixture in the influent to the activated sludge reactor, with examples in Ref. A-2.

TABLE A-3. SOLUBILITY OF HYDRACARBONS IN WATER
(From Reference A-7)

Hydrocarbon	Solubility Limit at 25°C, gm H/C per 10^6 gm water	Henry's Law Constant, psia per mole fraction
Methane	24.4 ± 1.0	537,000
Ethane	60.4 ± 1.3	406,000
Propane	62.4 ± 2.1	576,000
n-Butane	61.4 ± 2.6	772,000
Isobutane	48.9 ± 2.1	970,000
n-Pentane	38.5 ± 2.0	1,040,000
Isopentane	47.8 ± 1.6	1,006,000
n-Hexane	9.5 ± 1.3	1,430,000
2-Methylpentane	13.8 ± 0.9	1,420,000
3-Methylpentane	12.8 ± 0.6	1,380,000
2,2-Dimethylbutane	18.4 ± 1.3	1,600,000
n-Heptane	2.93 ± 0.20	1,650,000
n-Octane	0.66 ± 0.06	2,590,000
Ethylene	131 ± 10	175,000
Propylene	200 ± 27	172,000
1-Butene	222 ± 10	206,000
Propyne	3640 ± 125	8,990
Cyclopentane	156 ± 9	153,000
Cyclohexane	55 ± 2.3	168,000
Methylcyclohexane	14.0 ± 1.2	349,000
Benzene	1780 ± 45	4,580
Toluene	515 ± 17	5,560
o-Xylene	175 ± 8	4,310
Ethylbenzene	152 ± 8	7,130

TABLE A-4. SPILLS OF INDUSTRIAL WASTE CHEMICALS TO PRODUCE FLAMMABLE MIXTURES (from Ref. A-2)

Chemical	LEL Mole %	Liquid Concentration Mole Fraction	 mg/l	Required Spill gal/MM gal. waste
Acetone	2.6	0.012	36,000	48,000
Methanol	6.7	0.326	410,000	1,100,000
Ethanol	3.3	0.203	360,000	820,000
n-Propanol	2.2	0.779	750,000	14,600,000
n-Butanol	1.7	*	*	*

* cannot reach LEL until liquid is pure alcohol at 35°C

REFERENCES

A-1. McKinley, C.; "Oxygen Enriched Atmosphere Hazard in Wastewater Treatment. In: Proceedings of the Symposium on New Trends in Water and Sewage Treatment using Pure Oxygen and Ozone." Denver, Bureau of Reclamation, October 1974.

A-2. Baker, C. R. and R. V. Carlson; "Oxygen Safety Considerations, Use of Purified Oxygen in Secondary Wastewater Treatment." In: Chapter 15, Use of Purified Oxygen in Secondary Waste Treatment, 2 vols., Water Pollution Control Technology Series, Chemical Rubber Co., Cleveland, Ohio, 1975.

A-3. Coward, H. F. and G. W. Jones; "Limits of Flammability of Gases and Vapors," U.S. Bureau of Mines Bulletin 503 (1952).

A-4. Zabetakis, M. G.: "Flammability Characteristics of Combustible Gases and Vapors," U.S. Bureau of Mines Bulletin 627 (1965).

A-5. Stewart, P. B. and E. S. Starkman: "Flammability Limits for Hydrocarbons at Low Pressures," Chemical Engineering Progress 53, 41-J (1957).

A-6. Le Chatelier, H.; "Estimation of Firedamp by Flammability Limits," Ann. Mines 19, 388 (1891).

A-7. McAuliffe, Clayton: "Solubility in Water of Paraffin, Cycloparaffin, Olefin, Acetylene, Cycloolefin and Aromatic Hydrocarbons," J. Phys. Chem., 70, No. 4, 1267 (April 1966).